PUBLICATIONS

OF THE

Earthquake Investigation Committee

IN

FOREIGN LANGUAGES.

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Page 10, line 5 from bottom, insert, "'The symbols $2a$ and T denote respectively the double amplitude and the period of vibration.'"

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1. The great Mino-Owari and other recent destructive earthquakes gave excellent opportunities for studying the effects of the shocks on buildings and structures of engineering works. For discovering the best earthquake-proof form of the latter, however, it is also very important to investigate their vibratory movements caused by non-destructive earthquakes as well as by artificial means. Experiments like these, which depend upon practical applications of seismological instruments, form a part of modern seismology and furnish, apart from seismological questions, criterions on the strength and quality of the structures in general.

2. The present paper contains the results of the vibration and deflection measurements of 12 railway bridge girders in Central Japan and the Hokkaido, carried on during 1899 and 1900. The spans of these bridges, the majority of which are constructed according to the Imperial Japanese Government Railway Standard, vary between 20 and 200 ft. All the bridges, with the exception of that of the Rokugo-*gawa*, are constructed for a single railway line.

The importance of the bridge experiments is two-fold :— (1) the measurement of the deflection and vibration of a bridge gives a criterion of the strength of the latter, and accordingly a comparison of the results obtained from a number of differently constructed bridges may lead us to

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* Translation of Vol. XXXVII of the *Report* (Japanese) *of the Earthquake Investigation Committee.*

the discovery of the best forms in which the economy of material can be combined with the strength of structure ; (2) these experiments enable us to determine the variation of the strength of bridges with time and load. Indeed the circumstance, which first induced me to try the present series of experiments, was the question of stability of the Rokugo-*gawa* bridge, near Tokyo, which was constructed about 30 years ago and is the first large railway bridge constructed in Japan. At that date the locomotives were not so heavy as now-a-days ; hence it is of a great interest to examine the movements, particularly the deflection of the bridge in the present daily traffic.*

I shall here, for the sake of clearness, define *deflection* and *vibration* as follows : (1) the *deflection* of a bridge girder is the total amount of its vertical bending caused by the passage of a locomotive or wagons ; (2) the *vibration* is the quick-period motion of the girder due to the passage of a train or other cause. The *vibration* takes place in three mutually rectangular directions and may be distinguished as the *vertical, transverse* and *longitudinal*, of which the first consists of the up and down movements, while the second and third consist of the horizontal movements respectively transverse and parallel to the length of the bridge. It will be observed that the *vibrations* caused by a railway train are greatest when the speed of the latter has a certain value and almost *nil* when the speed is very slow. Hence the deflection will be greater when the locomotive is passing over with a certain speed than when passing over slowly or remaining at rest at the middle of the span ; the deflection being the sum of the statical bending due to the weight of the locomotive and the amplitude of the coexisting vertical vibration. Hitherto the phenomena of the vibration have by engineers not been taken into account, but they seem to be of fundamental importance with regard to the construction of the bridges.

* Before me, Professor Ewing obtained statical diagrams of the horizontal movements of the Forth Bridge in Scotland, by means of a duplex pendulum seismograph. In Japan, Messrs Milne and Macdonald measured with a glass-plate seismograph the *vibration* of the Rokugo-*gawa* and Tone-*gawa* railway bridges.

I may here remark that the part of the deflection due to the weight of the engine will be independent of the velocity of passage of the latter. Thus an engine requires, even in the cases of express trains, a time interval of at least 2 to 4 seconds to pass over girders 100′ to 200′ long while the period of the vertical vibration is usually less than $\frac{1}{3}$ sec., being considerably shorter than the above interval.

In my experiments, the deflection and vibrations of a bridge are directly recorded by instruments of portable form set up on the latter itself, requiring no support to be erected from the bed of the rivers. The measurement is thus possible even when there is abundant water in the river or when the bridge is very high; excepting in the cases in which the time of passage of the locomotive over the girder is very long, when the deflection can not be satisfactorily measured. The measurement of the vibrations is possible under all circumstances.

I shall next describe shortly the two instruments, which may, for the sake of convenience, be respectively called the *deflectometer* and the *vibration measurer*, according as they are intended for the measurement of the deflection or the vibrations of bridge girders.

3. *Deflectometer*. The deflectometer is exactly the vertical motion seismograph of Gray and Ewing,* with some improvements in the construction details so as to reduce very much the friction existing between the different parts of the instruments and, at the same time, to bring the *steady point* sufficiently near to the condition of neutral equilibrium, that is to say, to prolong its period of free oscillation; the deflection being measured as a very slow vertical vibration.† The instrument, mounted in working order, is shown in Fig. 1,‡ while its mechanical details are given in Pl. I at the end of the paper.

* For the description and theory of the original forms of the vertical motion seismograph, the reader is referred to *Trans. Seis. Soc. Japan*.

† The apparatus is thus well fitted also for the registration of microseismic vertical movements, if the steady point has a sufficient amount of inertia.

‡ Set up on the bottom chord of one of the 100′ Warren girders of the Akabane Bridge, near Akabane, of the Nippon Railway Company.

Pl. I. *a* is a stout cast iron stand, about 60 cm in height, fixed by means of two bolts *b* to the strong rectangular wooden base plate *c*, about 30×60 cm in size on which the record-receiver *d* is mounted. The *steady line* is the central axis of a small horizontal brass cylinder *e*, filled with lead, about 1 kg in weight, which is adjustable along and can be properly fixed at the end of a horizontal bar *f* by means of a screw *g*. The bar *f* is about 30 cm long and its end half ff_1 consists of a solid aluminium rod, about $\frac{3}{4}$ cm in diameter, rigidly fixed to the point of a brass triangular plate f_1f_2, whose base is turned towards the cast iron stand. The rod *f* is maintained in the horizontal position by being kept against the points of the two fine steel screws *hh* fixed to the stand and by being pulled upwards with the two spiral springs *ii*. The latter are suspended from the top of the stand by means of two vertical screws *jj*, the upper ends being rigidly fixed by two small side screws (not shown in the figures). The lower extremities of the two springs are firmly attached to the ends of a small horizontal brass rod *k*, which is at right angles to the rod *f*, and is kept at a little distance below the latter by means of another fine steel screw *l*, which fits into a conical socket of hardest steel at the middle of *k*. The screw *l* is adjustable some small distance along the central axis of the rod *f*. One of the two screws *hh* fits also into a conical socket of hard steel, while the other fits into a V-groove also of hard steel, both fixed on the brass plate f_1f_2 near its base. The V-groove which is parallel to the base side of the plate is adjustable through a small distance longitudinally. The two screws *hh* keep the horizontal rod f_1f_2 in position and also serve to regulate the elastic force of the spiral springs; the adjustment of the latter is, however, to be done most conveniently by means of the two top screws *jj*. The screw *l* serves, by being gradually screwed on, to set the weight *e* in a *neutral equilibrium*, that is to say, to make the period of free oscillation of the pendulating system f_2f sufficiently long, without being thrown into the condition of unstable equilibrium. The most important point in the treatment of the apparatus is to keep the points of the three screws *h*, *h* and *l* perfectly well polished and sharp; the vertices of the two conical sockets and the V-groove, into which the three screws respectively

Fig. 1.

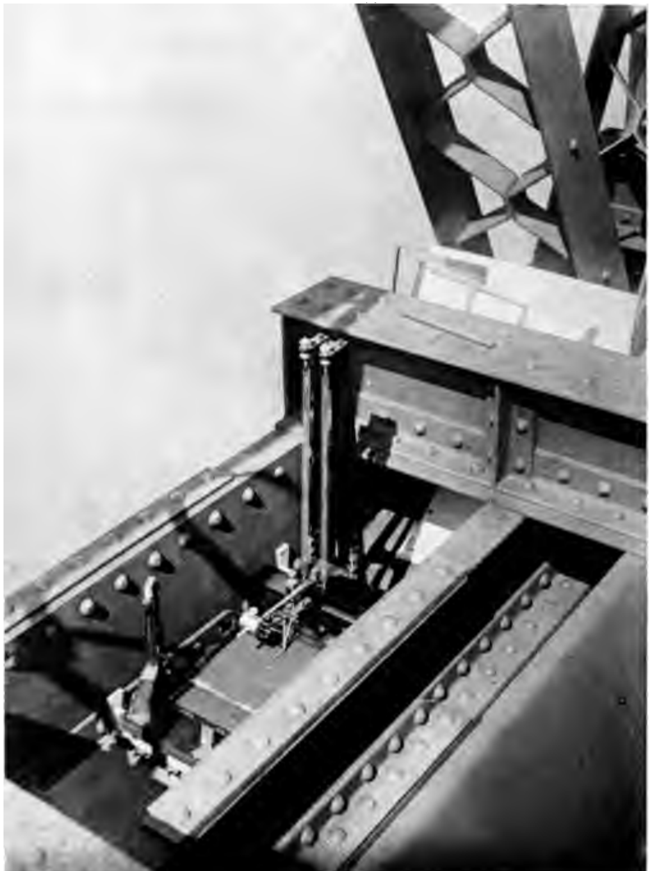

Fig. 2.

Deflectometer (Fig. 1) and Vibration Measurer (Fig. 2) set up on the Arakawa Bridge 100′ Warren Girder, Nippon Railway.

Fig. 3. The 1st Ishikari-*gawa* Bridge 200′ Double Warren Girder.

fit must also be perfectly well formed. If the points of the three screws be broken or flattened, or if their receptacles be scratched, the period can no longer be made slow as is necessary for the deflection measurement. For this reason, each instrument is furnished with one or two extra sets of the screws, to provide for the case of accidental damage of their points, when the new ones are to be at once substituted for the old. Again the longitudinal sliding of the V-groove enables us to use a new portion of the vertex line in case of its old position being scratched. The two screws m m, whose ends are covered with india-rubber pieces, are fixed to an upright bracket attached to the wooden base plate c and prevent too great motion of the pendulating system f_2f. With apparatus of this dimension, I succeded within the limit of sufficient stability, in raising the period of free oscillation of the *steady mass* up to about 15 seconds; it being very easy to make the period 8 or 9 secods.

The writing index. For reducing effectively the friction between the different parts of the instrument, which is absolutely necessary for the deflection measurement, I have used the same method of contact between the steady axis and one of the arms of the pointer as in my mechanically registering horizontal pendulums for the observation of earthquakes.* The writing pointer is made up of a lever, whose two arms mm_1 and mm_2 are bent at right angles to one another, and whose fulcrum m consists of a horizontal small steel axis pivoted in the conical sockets of the two small horizontal screws; these screws are fixed to a bracket m_3, properly mounted on a wooden stand n, which is rigidly attached to the base plate c.† The horizontal arm mm_1 is made of thin but sufficiently stout brass strips with a forked end, within whose two limbs fits exactly a highly polished steel cylindrical axle, forming the prolongation of the central line of the heavy mass e. The axle can rotate with great ease, being pivoted within two

* See *Publications of the Earthquake Investigation Committee in Foreign Languages*, Nos. 5 and 6, and *Jour. Sc. Coll., Imp. Univ., Tokyo, Vol. XI.*

† In other apparatus the bracket, which holds the fulcrum m_3, is adjustable in direction parallel to the rod f_2f_1, thus enabling us to change the multiplying power of the pointer, between 1 and 2.

small steel conical sockets, fixed respectively to the centre of one of the ends of the heavy cylinder e and to a bracket m_4 attached to the latter. The vertical arm mm_1 of the lever is made up of a triangular frame of aluminium, with the axle as the base; the writing index m_5, hinged to the lower end m_2 being made of a very light steel piece of a triangular form, with its end point very well polished. The length of the index m_5 is 5 cm. For the instrument designed to measure the deflection of 200′ trusses, the two arms mm_1 and mm_2 are each 8 cm long, thus giving the deflection nearly in the natural magnitude. For bridge girders of length under 100′, it is convenient to make the two arms mm_2 and mm_1 respectively 8 and 4 cm long, thus giving a multiplication of about 2. It is hereby to be remarked that we must apply a slight correction to the nominal multiplication, or the ratio of the arms mm_2 and mm_1, on account of the motion of the hinge m_2 not being perfectly horizontal. The correction can easily be found graphically by means of section paper. The centre of gravity of m_1mm_2 is brought almost exactly on its fulcrum m by means of two small counter weights, so that the pointer has practically no proper oscillation. If this adjustment be not properly cared for, the motion of the pointer would markedly interfere with the stability of the *steady mass* e and might cause the latter to swing quickly even if adjusted beforehand to a very slow period.

The *record receiver* is the same as that in Prof. Tanakadate's seismograph and consists of a smooth paper smoked with a petroleum lamp, wrapped round two parallel rollers d, one of which is driven by means of a clock work d_1. The paper revolves across the index m_5 at a rate of about 3 cm per second and has at the same time a translation motion, the axes of the two rollers being screw cut.

The *time-recorder* consists of a small pendulum oo_1, of which the heavy mass o_1 weighs about 100 grm; the pendulum is of such a length that it makes about $1\frac{1}{2}$ complete oscillations in 1 second. The prolongation o_2 comes in contact with, and presses against one of the arms of a light spring lever each time the pendulum oscillates to and fro, thus lifting the end o_4 of the other arm of the lever, the fulcrum of which is an axis hinged

to the support of the pendulum. The very small spiral spring o_5 is attached to the arm o_4, its stretching force being adjusted with a screw (not shown in the figure). By this means the pendulum oo_1 can be caused to oscillate for about 1½ m, a time mark being made each time o_4 is uplifted. From the knowledge of the period of oscillation of the pendulum, which is constant, the period of the bridge vibrations can be accurately determined.*

When there is no motion, the writing index of the pointer, m_5, traces out a straight (or rather a spiral) line, parallel to that given by the time-ticker index o_4. The latter line may be taken as the fixed or datum line, with reference to which the deflection is to be measured. After the deflection has been traced out, there follows generally proper pendulum oscillations of the *steady mass* on account of the displacement, but these movements can be left out of account so far as the deflection measurement is concerned.

For the satisfactory use of the deflectometer, the period of free oscillation of the steady mass must be much longer than, say about twice as long as, the time required by the locomotive to pass over the girder under experiment. In the case of ordinary trains in Japan, a 100′ span, for instance, is passed over by a locomotive in a time interval from 1½ s to 5 s, according as the train runs quickly or very slowly. For spans under 100′ there is therefore no difficulty in measuring the deflection by the instrument. With 200′ trusses, the experiment fails unless the locomotive passes over in at most 4 to 5 seconds.

4. *Vibration measurer or strong motion seismograph.* This vibration measurer, which is shown in Pl. II, can also, when properly connected with a starter, be used as a seismograph for the measurement of strong earthquakes. Fig. 2 is the photograph of the instrument set up on the bottom chord of one of the 100′ Warren girders of the Akabane-*gawa* bridge of Nippon Railway Company.

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* The purely mechanical process of time marking without aid of electricity and mercury contact was first done by Prof. Tanakadate.

In the vibration measurement, one of the most important conditions is the elimination of the proper oscillation of the steady masses themselves. The best thing to be done is, as already elsewhere remarked, to increase the inertia and to prolong the period of free oscillation of the pendulums, so that we can easily distinguish the real bridge vibrations from the proper instrumental oscillations, if any. For our present purpose, the required length of the period of the horizontal pendulums is 4 or 5 s, which can very easily be attained. If these circumstances be not properly attended to, the proper instrumental oscillations may be mistaken for the real movements we are seeking; and the range of motion of the former may amount to several inches, while that of the latter may be less than one mm.

5. In transportation, the vertical motion instrument and the horizontal pendulums are to be taken off and packed up. The unpacking and the setting up of the two instruments, when skilfully carried on, can be accomplished in less than one hour. The manner of setting on the bridges will be seen from Figs. 1 and 2 already referred to; also from Fig. 3, which represents the 1st Ishikari-*gawa* bridge, 200′ Double Warren girder.

With Warren girders, the instruments can be fixed most conveniently in the box of one of the bottom chords. But in some of the Pratt trusses and plate girders, we must set up the apparatus within the stringer or the girder itself, below the rails and sleepers, the observer himself getting also therein and waiting the passage of the train overhead. The base plates of the instruments are to be rigidly fixed to the bridge girder by means of wooden bars and properly prepared bolts. In the present series of the bridge experiments, the measurement was in each case done at the middle of the span.

6. *Bridges.* I shall now give the results of the deflection and vibration measurements of the following 11 bridge girders.

(1) Rokugo-*gawa* bridge: 100′, I. J. G. Railway.

(2) Chubetsu-*gawa* bridge: 100′, Hokkaido Gov. Railway.

(3)	3rd Ishikari-*gawa* bridge	: 100′,	Hokkaido Gov. Railway.
(4)	1st Ishikari-*gawa* bridge	: 200′,	" " "
(5)	2nd " " "	: 20′,	" " "
(6)	" " " "	: 70′,	" " "
(7)	Chubetsu " "	: 60′,	" " "
(8)	Osarappe " "	: 50′,	" " "
(9)	Kanasugi " "	: 30′,	I. J. G. Railway.
(10)	Ibi " "	: 200′,	" " "
(11)	Kizu " "	: 200′,	Kansei Railway.

The vibratory motion of a bridge consists, as an earthquake, generally of the following three parts: (1) the *preliminary portion,* in which the motion is small and occurs with the approach of the train to the girder; (2) the *principal portion,* in which the motion is most active and generally coincides with the passage of the train or engine over the girder under experiment; (3) the *end portion* in which the motion is small, being the residual vibrations continued for a certain interval of time after the train has passed over the girder.

The vertical, transverse or longitudinal motion of a bridge girder consists, in general, of the *fundamental vibrations* of a period which is proper to the girder itself. Besides these there are extremely quick, and usually, much smaller movements which are due probably to the vibrations of the individual members of the girder and which may be termed *micro-vibrations.*

To specify the vibration of a girder, I have given in each case the maximum range of motion, or double amplitude, and the average period. The latter quantity is obtained by taking the average of a certain number of consecutive and nearly equal vibrations.*

Pl. III to XII give diagrams of the deflection and vibration of some of the bridges; while Pl. XV to XXI give the distances between the wheels and the distribution of weight of the engines, which passed over the different bridges during the experiments.

* The term *period* is used always in the sense of the *complete period.*

Rokugo-gawa Bridge: Double Track Warren Girder through 100′.

7. The main portion of the double track Rokugo-*gawa* bridge, which is on the Tokyo-Yokohama line, consists of six Warren trusses through 100′. The experiments were done on three different days, namely, Oct. 19th and 25th, 1899, and Feb. 5th 1900; and each time the apparatus were set up at one and the same place, in the middle of the span on the left-hand or down-stream side bottom chord of the first span (counted from the Tokyo end). As the down trains pass on the left-hand side and the up trains on the right-hand side of the bridge, the former gave in the present experiments always greater deflections than the latter; there being, however, no such distinction in case of the vertical, transverse and longitudinal vibrations. Again, it is to be remarked that on the Yokohama side of the bridge there is a descending slope of 1 : 100, while the track is almost level on the Tokyo side, where there are a series of 60′ plate girders. The Kawasaki Station lies on the Yokohama side at only a few hundred metres distance from the bridge. Thus the down trains passed over the bridge quickly, while the up trains passed over always slowly.

The trains and engines which passed over the bridge during the experiments were as given in the following table.

TABLE I.

ROKUGO-*GAWA* BRIDGE EXPERIMENTS: TRAINS AND ENGINES.

Date of experiment.	No. of expt.	Train.	No. of train.	No. of engine.	Engine.	Total weight of engine.	weight of tender.
						t	t
Oct. 19, 1899.	1	Down.	115 (11 passenger cars).		Tender engine.	50.88	21.97
	2		Special goods train.				
	3		243 (10 passenger cars).		Tank engine.	33.43	—
	4		439 (36 goods wagons).		,,	,,	—
	5		245 (9 passenger cars).		Tender engine.	49.9[illegible]	19.39
	6	Up.	222 (10 ,, ,,).		Tank engine.	33.43	—
	7		224 (16 ,, ,,).		Tender engine.	52.78	22.73
	8		102 (11 ,, ,,).		Tank engine.	33.43	—
	9		402 (23 goods wagons).		,,	,,	—
	10		226.				
Oct. 25, 1899.	11	Down.	115.	205	Tender engine.	48.70	21.00
	12		Special goods train.				
	13		243.	114	Tank engine.	33.43	—
	14		439.	91	,,	,,	—
	15	Up.	222.	62	,,	,,	—
	16		224.	242	Tender engine.	61.00	26.00
	17		102.	243	,,	,,	—
Feb. 5, 1900.	18	Down.	221 (11 passenger cars).				
	19		115 (,, ,, ,,).	111	Tank engine.	48.90	—
	20		Special goods train, (15 goods wagons).	61	,,	33.43	—
	21		243 (10 passenger cars)	98	,,	,,	—
	22		439 (20 goods wagons).	119	Tender engine.	48.79	21.00
	23	Up.	100.	,,	,,	,,	,,
	24		222 (11 passenger cars).	109	Tank engine.	48.90	—
	25		224 (15 ,, ,,).	70	,,	33.43	—

8. (*a*) *Experiments on Oct. 19th and 25th, 1899; deflection directly measured.* On these two days, the deflectometer was not yet ready, and consequently the deflection was directly measured at the river bed, which was dry, with the following arrangement: a heavy lead cylinder, weighing about 10 kg, was suspended by means of a surveying chain from the middle of the bottom chord of the girder, and its movements were registered with a suitable arrangement on a record receiver set up at the river bed beneath.* The height of the bottom chord above the river bed was about 20′. (A few of the diagrams thus obtained are reproduced in Fig. 7.) The results of the experiments are given in the following table, where d_1 and d_2 are the deflections of the girder at the middle of the left-hand side bottom chord due respectively to the engines and the goods or passenger cars.

* The record receiver was similar to that described in § 2.

TABLE II.

ROKUGO-*GAWA* BRIDGE EXPERIMENTS : DEFLECTION DIRECTLY MEASURED.

No. of expt.	No. of train.	d_1 (mm)	d_2 (mm).
	Down Trains.		
1	115	9.5	3.7
2	Special goods train.	7.8	4.0
3	243	8.2	3.7
4	439	8.4	7.0
5	245	10.8	5.2
11	115	10.6	5.2
12	Special goods train.	8.1	4.6
13	243	8.0	3.3
14	439	8.8	7.2
Mean.	....	8.91	4.88
	Up Trains.		
6	222	3.8	1.7
7	224	4.0	1.0
8	102	3.8	1.7
9	402	3.7	2.9
10	226	4.6	—
15	222	4.4	2.4
16	224	5.7	2.6
17	102	4.6	2.5
Mean.	....	4.33	2.11

The results contained in the above table may be summarized as follows.—

The mean value of the deflection d_1 due to the locomotives is, in the case of the down trains, 8.91 mm and, in the case of the up trains, 4.33 mm ; the two numbers being in the ratio of nearly 2 : 1. With respect to the deflection d_2 due to the goods or passenger cars, the mean values are 4.88 mm and 2.11 mm respectively for the down and the up trains

Again, the mean value of d_1 is about double that of d_2, both for the down and the up trains.

Of the experiments 1-17, the maximum value of the deflection d_1 was for the down trains 10.8 mm and for the up trains 5.7 mm. The sum of these two maximum deflections, which is 16.5 mm or about $\frac{5''}{8}$, may be taken as representing the maximum amount of deflection of the 100′ girder, if two of the heaviest engines in the present state of the traffic on the Tokyo-Yokohama Railway, one in the down train and the other in the up train, were to pass by each other exactly at the middle of the span. This amount is about 5 mm greater than the maximum deflection of the 100′ Pratt trusses of the 3rd Ishikari-*gawa* in Hokkaido when tested with two heavy tank engines in series.

The maximum value of the deflection d_2 due to the goods wagons was 7.2 mm for the down trains and 2.9 mm for the up trains, their sum being 10.1 mm. Again, the maximum value of the deflection d_2 due to the passenger cars was 5.2 mm for the down trains and 2.6 mm for the up trains, their sum being 7.8 mm. These two sums, representing the deflections which would be caused by heaviest goods wagons and passenger cars of the down and up trains, if they were to pass by each other exactly at the centere of the 100′ girder, are respectively $\frac{6}{10}$ and $\frac{4.7}{10}$ of the corresponding sums in the case of the locomotives. The deflection due to heavy goods wagons is nearly equal to that due to small locomotives.

9. (*b*) *Experiments on Oct. 19th and 25th, 1899 ; the vertical, transverse and longitudinal vibrations.* On these two days, I measured, besides the deflection, also the vibrations of the bridge by means of the *vibration* measurer set-up at the middle of the left-hand side bottom chord of the same 100′ girder. The results were as follaws.—

Down trains.

Exp. No. 2.

Vert. vib. The motion lasted for 36 secs. and the max. 2a was 1.2 mm ; the amplitude remaining, however, sensibly constant throughout.

In the principal portion, namely, during the passage of the locomotive over the girder, the average period was 0.24 sec.; in the end portion, at 20 secs. after the entrance of the engine on the girder the average period was 0.23 sec. At the entrance of the locomotive on the girder as well as at other times, there were also quicker vibrations; the average periods of these, measured in the preliminary and the end portions, were respectively 0.11 sec. and 0.13 sec. There were also traces of still smaller movements.

Trans. vib. The max. 2a was 3.5 mm; the amplitude remained, however, nearly constant throughout the whole duration. The average period was 0.49 sec. when the locomotive was passing over and 0.45 sec. in the end portion.

Long. vib. The total duration was 36 sec. The max. 2a was 0.5 mm; there being, however, no marked alteration of amplitude throughout the motion. In the end portion, the average period was 0.089 sec. (In all the three components, there were some slight micro-vibrations superposed on the fundamental vibrations.)

Exp. No. 3.

Vert. vib. The max. 2a was 1.1 mm, the average period in the principal portion being 0.17 sec. The fundamental vibrations were superposed with movements of an average period of 0.03 sec. and other still smaller ones.

Trans. vib. The max. 2a of 2.7 mm took place when the locomotive had just entered on the girder. The average period was 0.42 sec. in the principal portion and 0.41 sec. in the end portion.—In this experiment the vibrations were comparatively small, the active motion lasting only for 8 sec. The max. vertical and longitudinal displacements also occurred at the moment of the entrance of the locomotive on the girder.

Long. vib. The max. 2a was 0.5 mm; the average period in the end portion being 0.08 sec.

Exp. No. 4.

Vert. vib. The max. 2a was 1.3 mm. In the principal portion the average period was 0.19 sec. at first, but 0.23 sec. a little later on. In the end portion it was 0.14 sec.

Trans. vib. The motion was active and nearly constant during the first 18 sec. after which it became abruptly much smaller. The max. (absolute) 2a of 5.3 mm occurred 14 secs. after the entrance of the locomotive on the girder; the greatest motion *during* the passage of the locomotive being only 2.7 mm. The average period was 0.58 sec, in the most active portion and 0.38 sec. in the end portion, while during the passage of the locomotive it was 0.53 sec.

Long. vib. The max. 2a was 0.5 mm; the range remaining nearly constant in amplitude during the whole motion, which lasted for 20 sec. The average period was 0.074 sec. when the locomotive was just passing out of the girder, and 0.073 s in the end portion.

Exp. No. 5.

Vert. vib.	The max. 2a was	1.2 mm.
Trans. vib.	„ „ „ „	4.7 „
Long. vib.	„ „ „ „	0.4 „

Exp. No. 12.

Vert. vib. The motion lasted for 23 sec. during which the amplitude remained almost constant. The max. 2a of 1.6 mm ocurred at the entrance of the locomotive on the girder. The average period was 0.21 sec. in the principal portion and 0.18 sec. in the end portion. There were also some small vibrations of an average period of 0.09 sec.

Trans. vib. The max. 2a of 2.7 mm occurred at the entrance of the locomotive on the girder. The average period was 0.47 sec. in the principal portion and 0.48 sec. in the end portion. The max. range of the superposed micro-vibrations was 0.6 mm.

Long. vib. The max. 2a was 0.5mm, the period being extremely short.

Exp. No. 13.

Vert. vib. The max. 2a was 1.6 mm, the average period in the principal portion being 0.16 sec.

Trans. vib. The motion lasted for 13 sec. during which the amplitude was nearly constant. The max. 2a of 2.4 mm occurred at the entrance of the locomotive on the girder. The average period was 0.46 sec. in the end portion.

Long. vib. The max. 2a was 0.5 mm, the period being extremely short.

Up trains.

Exp. No. 8.

Vert. vib. The max. 2a was 0.7 mm.

Trans. vib. The motion lasted for 23 sec. during which the amplitude remained almost constant. The max. 2a of 3.0 mm occurred during the passage of the locomotive, the average period of the principal vibrations being 0.64 sec. Later on the average period was 0.47 sec. while in the end portion it was 0.41 sec.

Long. vib. The max. 2a was 0.5 mm.

Exp. No. 9.

Vert. vib. The max. 2a was 2.1 mm.

Trans. vib. „ „ 5.2 „

Long. vib. „ „ 0.4 „

Exp. No. 16.

Vert. vib. There were already some distinct movements before the locomotive came actually on the girder, the average period being 0.13 s. During the passage of the locomotive the average period was 0.17 sec, the max. 2a being 1.0 mm. The max. of the superposed micro-vibrations was 0.6 mm.

Trans. vib. The max. 2a of 4.6 mm occurred at the entrance of the locomotive on the girder. The average period was 0.22 sec. in the preliminary portion, 0.52 sec. in the principal portion and 0.42 sec. in the end portion.

Long. vib. The max. 2a was 0.5 mm, the period being extremely short.

Exp. No. 17.

Vert. vib. The max. 2a was 1.1 mm, the average period in the principal portion being 0.24 sec. There were superposed micro-vibrations of an average period of 0.053 sec. and others still smaller.

Trans. vib. The max. 2a was 2.7 mm, the average period being 0.48s in the principal portion and 0.45 s in the end portion.

Long. vib. The max. 2a was 0.5 mm, the period being very short. Towards the end, there were some vibrations of an average period of 0.02 s.

Exp. No. 17′.

(This experiment was made on the 25th, but the numbers of the train and of the locomotive were not noted.)

Vert. vib. The max. 2a was 1.2 mm. The average period was 0.17 sec. during the passage of the engine, but 0.12 sec. before the entrance of the latter on the girder. There were also very small vibrations of an average period of 0.025 sec.

Trans. vib. The active movements lasted for 10 sec. during which the amplitude remained almost constant, and after which the motion abruptly decreased. The max. 2a was 2.9 mm, the average period being 0.59 sec. in the principal portion and 0.42 sec. in the end portion.

Long. vib. The max. 2a was 0.7 mm, the period being very short. Before the entrance of the locomotive on the girder, there were small vibrations of an average period of 0.12 sec.

The results of the above vibration measurements are summarized in the following table, where 2a is the maximum range of motion (or double amplitude) in each component, while T and T' are the average periods of vibration respectively in the principal portion and in the preliminary or end portion.

TABLE III.

ROKUGO-*GAWA* BRIDGE EXPERIMENTS:

VIBRATIONS.

No. of expt.	Vertical vibration. 2a (mm).	T (s)	T′(s)	Transverse vibration. 2a (mm).	T (s)	T′(s)	Longit. vib. 2a (mm).	T′(s)	Duration. (s).
				Down trains.					
2	1.2	0.24	{0.23 0.12	3.5	0.49	0.45	0.5	0.089	36
3	1.1	0.17	—	2.7	0.42	0.41	0.5	0.080	8
4	1.3	0.19	0.14	5.3	0.58	0.38	0.5	0.074	20
5	1.2	—	—	4.7	—	—	0.4	—	—
12	1.6	0.21	0.18	2.7	0.47	0.48	0.5	—	23
13	1.6	0.16	—	2.4	—	0.46	0.5	—	13
Mean.	1.3	0.19	—	3.6	0.49	0.44	0.5	0.081	—
				Up trains.					
8	0.7	—	—	3.0	0.64	0.41	0.5	—	23
9	2.1	—	—	5.2	—	—	0.4	—	—
16	1.0	0.17	0.13	4.6	0.52	{0.22 0.42	0.5	—	—
17	1.1	0.24	—	2.7	0.48	0.45	0.5	—	—
17′	1.2	0.17	0.12	2.9	0.59	0.42	0.7	0.12	10
Mean.	1.2	0.19	—	3.7	0.56	{0.43 0.22	0.5	—	—
General Mean.	1.3	0.19	—	3.7	0.53	{0.43 0.22	0.5	{0.081 —	—

According to the above table, the three component vibrations at the middle of the left-hand side bottom chord of the girder were, on the whole, equally large for the down and the up trains.

Vertical vibration. The max. range of the vertical vibration was 2.1 mm, and the max. motion likely to occur, were the down and the up trains to pass simultaneously over the girder, would be 3.7 mm as is to be inferred from the table. The average period of vibration in the principal portion varied between 0.16s and 0.24s, the mean value being 0.19s.

In the preliminary and the end portions there were also often other vibrations of an average period between 0.12s and 0.14s.

Transverse vibration. The max. range of the transverse vibration was 5.3 mm, and the motion for a simultaneous passage of the down and the up trains would be 10.5 mm. The average period in the principal portion varied between 0.42s and 0.64s, the mean value being 0.53s. In the preliminary and end portions, there were two kinds of vibrations whose average periods were respectively 0.43 s and 0.22s.

Longitudinal vibration. The max. range of the longitudinal vibration was almost always 0.5 mm. The period was very short, but in the preliminary and end portions there were often some vibrations whose average period was 0.081 s.

The *duration* varied between 8 and 36 s.

The variation in the different cases of the period of the vertical and transverse vibrations is due to the difference in the weights of the engines and the number and weight of the goods or passenger wagons.

10. (c). *Experiments on Feb. 5th 1900; deflection and vertical vibration.* On this day, the deflectometer was used for the first time and set up as usual at the middle of the left-hand side bottom chord of the first 100′ girder. For testing the accuracy of the deflectometer, a special arrangement was made at the river bed, so that the deflection was dirctly measured by means of an upright wooden beam erected beneath the instrument. The values of the deflections thus found are given under the heading " check " in the following table ; a few diagrams obtained by the deflectometer being given, as illustrations, in Pl. V and VI.

TABLE IV.

ROKUGO-*GAWA* BRIDGE EXPERIMENTS; DEFLECTION AND VERTICAL VIBRATION.

No. of expt.	Deflection.		Vertical Vibration.	
	Measured on the bridge by the deflectometer. (mm)	Measured directly. "Check." (in mm)	Max. 2a. (mm)	Average period. (sec.)
		Down trains.		
18	11.4 mm	$\frac{15''}{32}$ = 11.9 mm	1.0	—
19	8.5	$\frac{5''}{8}$ = 9.5	1.0	0.21*
20	9.1	$\frac{5''}{16}$ = 7.9	1.3	0.21*
21	9.8	$\frac{11''}{32}$ = 8.7	1.2	0.22*
22	9.4	$\frac{7''}{16}$ = 11.0	1.5	0.25
		Up trains.		
23	3.8	$\frac{5''}{32}$ = 4.0	0.9	0.13
24	4.3	$\frac{5''}{32}$ = 4.0	0.5	0.20*
25	3.5	$\frac{5''}{32}$ = 4.0	0.6	0.22*
Mean.	7.5	7.6	—	0.22 (Expt. No. 23 omitted.)

In these experiments, the engines of the down trains passed over the girder in 2 to 3 seconds, while those of the up trains passed over the same in 4 to 5 seconds. According to the above table, however, the deflections given by the instrument set up on the bridge itself were practically identical with the "check," both in the cases of the down trains and the up trains, the mean values for the two sets of the determination being perfectly the same. The "checks" were originally read off in inches, from which the mm equivalents have been deduced.

Vertical vibration. The vertical motion seems to be greater in the case of the down than in the case of the up trains. The average period given in the table is that of the vibrations in the principal portion, the general mean being 0.22s. In the 5 cases marked with *asterisks* (*), however, there were vibrations of an average period of 0.13s in the preliminary portion. In experiment No. 23, the average period in the principal portion was also 0.13s. Finally, in the case of the up trains, there were no marked differances in the amplitude of vibration in the principal and in the preliminary portion.

Hokkaido Government Railway Bridges.

11. The experiments on the seven Hokkaido Gov. Railway bridges were carried on during the six days Oct. 8th-13th, 1900. The bridges and the engines were as given in the following two tables.

TABLE V.

HOKKAIDO GOV. RAILWAY BRIDGES.

River.	Bridge.	Remark.
Chubetsu.	Pratt truss through 100′	Designed by Prof. Tanabé and Mr. Eda.
3rd Ishikari.	"	"
1st Ishikari.	Double Warren truss through 200′.	I. J. G. R. Standard.
2nd Ishikari.	Plate girder deck 20′.	"
"	" " " 70′.	"
Chubetsu.	" " " 60′.	"
Osarappe.	" " " 50′.	"

TABLE VI.

HOKKAIDO GOV. RAILWAY ENGINES.

No. of engine.	Engine.	Total weight.	Weight of tender.
1	Tender engine.	50.1 t	18
2	"	"	"
6	Tank engine.	33.45	—
7	"	"	—
9	"	34.1	—
10	"	"	—

The vibrations were in all cases measured by means of the *vibration measurer*, while the deflections were measured by means of the *deflectometer*. In the cases of the two short girders, namely, the Oserappe-*gawa* 50′ and the 2nd Ishikari-*gawa* 20′ bridges, the deflections were also measured by the vibration measurer. When, in these cases, the deflections were simultaneously measured by the two instruments, the mean values have been adopted. The experiments are next described in detail. (See Pl. VIII–XII.)

12. *Chubetsu-gawa Bridge ; 60′ plate girder.*

Exp. No. 1.

Down train ; Engine No. 9. (As the train passed over while the instruments were not fully set up, the deflection and vertical vibration could not be measured.)

Trans. vib. The max. 2a was 3.8 mm. The average period was 0.30s in the principal portion and 0.29s in the preliminary portion, there being also some micro-vibrations of an average period of 0.04s.

Long. vib. The max. 2a was 1.7 mm, the period being very short. There were some trace of comparatively slow movements of an average period of 0.15s.

Exp. No. 2. 3 men together ran over the girder.

Vert. vib. (not measured.)

Trans. vib. The max. 2a was 0.3 mm, the average period being 0.29s.

Long. vib. *Nil.*

13. *Chubetsu gawa Bridge ; Pratt truss through 100′.* The experiment was done only once. Up train ; Engine No. 9 passed over the girder in 4s.

Deflection = 8.8 mm.

Vert. vib. The max. 2a was 1.2 mm, the average period of the principal vibrations being 0.25 s. There were also micro-vibrations of an average period of 0.032 s.

Trans. vib. The max. 2a was 3.3 mm. In the principal portion, the fundamental vibrations had an average period of 0.53 s, and on these

were superposed movements of an average period of 0.29s. Towards the end, the motion became simple in character and consisted of regular vibrations of an average period of 0.29s. Besides these movements, there were slight micro-vibrations of an average period of 0.033s.

Long. vib. The max. 2a was 1 mm.

14. *The 3rd Ishikari-gawa Bridge: Pratt truss through 100′.* The bridge consists of two Pratt trusses through 100′. On Oct. 10th 1900, at the completion of the construction, the bridge was tested by means of two similar tank engines Nos. 6 and 7 joined in series. The experiments were repeated four times; in the first two, however, the deflection could not be measured on account of an extremely slow rate of motion of the engines. The instruments were set up at the middle of the 100′ span next to the Asahigawa end.

Exp. No. 1. The engines passed over slowly.

Vert. vib. The max. 2a was 0.7 mm. The average period was 0.18s in the principal portion and 0.20s in the end portion. There were also slight micro-vibrations of an average period of 0.027s.

Trans. vib. The max. 2a was 2.4 mm, the average period being 0.51s. There were also slight micro-vibrations of an average period of 0.023s.

Long. vib. The motion was extremely small.

Exp. No. 2. (Same as before.)

Vert. vib. The max. 2a was 0.6mm, the average period being 0.22s.

Trans. vib. The max. 2a was 2.9mm, the average period being 0.79s.

Long. vib. The motion was extremely small.

Exp. No. 3. The two engines passed over the girder in 5.1s.

Deflection = 11.1 mm.

Vert. vib. The max. 2a was 1.2mm, the average period being 0.22s.

Trans. vib. The max. 2a was 4.9mm, the average period being 0.47s. There were also extremely small micro-vibrations.

Long. vib. The max. 2a was 1.4mm, the period being extremely short.

Exp. No. 4. The two engines passed over the girder in 5.2s.

Deflection = 12.0mm.

Vert. vib. The max. 2a was 1.4mm, and the average period was 0.21s.

Trans. vib. The max. 2a was 4.0mm, and the average period was 0.51s. There were also micro-vibrations of a very short period.

Long. vib. The max. 2a was 1.4mm, the period being extremely short.

15. *The 2nd Ishikari-gawa Bridge; 70′ plate girder.* The experiments were carried on between 10 a.m. and 3 p.m., on Oct. 11th 1900. In the morning there were some occasional showers, but in the after-noon the weather became clear and calm. The instruments were set up at the middle of the girder next to the Asahigawa end.

Exp. No. 1. The engine (No. 6) passed over the girder in 3.1s.

Deflection = 11.0mm.

Vert. vib. The max. 2a was 1.5 mm.

Trans. vib. The max. 2a was 3.9mm, the average period being 0.38s.

Long. vib. The max. 2a was 1.1 mm, the period being very short. Before the entrance of the locomotive on the girder, there were slight slow movements of an average period of 0.16s.

Exp. No. 2. The engine (No. 2) passed over the girder in 3.2s.

Deflection = 11.4 mm.

Vert. vib. The max. 2a was 1.5 mm.

Trans. vib. (The aluminium pointer of the tranverse component machine was broken and consequently the max. 2a not measured.)

Long. vib. The max. 2a was 1.7 mm, the period being very short.

Exp. No. 3. The engine (No. 10) passed over the girder in 3.6s.

Deflection = 9.9 mm.

Vert. vib. The max. 2a was 1 mm, the average period in the principal portion being 0.19s.

Trans. vib. The max. 2a was 3.3 mm and the average period of the principal vibrations was 0.37s; there being also micro-vibrations of an extremely short period. As is generally the case, these two series of

movements did not indicate their maxima simultaneously, but the maximum of the micro-vibrations occurred later than that of the principal vibrations. Thus the former vibrations became first prominent at 0.2s after the occurrence of the maximum of the latter, the most active portion occurring 2s further on. This peculiarity was also found to be the case in the longitudinal component.

Long. vib. The max. 2a was 1.0 mm, the period being very short.

Exp. No. 4. The engine (No. 10) passed over the girder in 3.4s.

Deflection = 6.6 mm.

Vert. vib. The max. 2a was 1 mm, and the average period was 0.18 s.

Trans. vib. As, in this case, the number of the wagons was few, the diagram was very simple and nice. The principal portion was well marked and consisted of 6 well defined, nearly equal vibrations which together occupied 2.2s and of which the max. 2a was 4.4 mm; the average period being 0.36s. The principal portion was almost perfectly free from the superposition of micro-vibrations. In the preliminary portion, there were small vibrations of an average period of 0.370s; in the end portion, the average period was 0.38s. The micro-vibrations became prominent first after the termination of the principal vibrations, the longitudinal movements becoming also prominent at the same moment.

Long. vib. The max. 2a was 0.5 mm, the period being very short. In the preliminary portion, that is to say, before the appearance of these quick vibrations, there were slower small movements of an average period of 0.17s.

Exp. No. 5. The engine (No. 10) passed over the girder in 3.0s.

Deflection = 6.5 mm.

Vert. vib. The max. 2a was 1 mm, the average period being 0.19s.

Trans. vib. The max. 2a was 2.8 mm, and the average period was 0.43s. In the preliminary portion, the motion consisted of small movements of an average period of 0.21s. In the principal portion and especially in the end portion, there were also vibrations of an average period of 0.20s.

Long. vib. The max. 2a was 1.7mm, the period being very quick.

Exp. No. 6. 3 men together walked slowly once over the girder. (In Exp. Nos. 6, 7 and 8, the vertical vibration was not measured.)

Trans. vib. The max. 2a was 0.3 mm, the average period being 0.38s.

Long. vib. *Nil.*

Exp. No. 7. 2 men together ran once over the girder.

Trans. vib. The max. 2a was 0.3mm, the average period being 0.38s.

Long. vib. *Nil.*

Exp. No. 8. Effect of a moderate wind.

Trans. vib. The motion was very small, the average period being 0.39s.

Long. vib. *Nil.*

It is to be remarked that bridges execute generally more or less movements when wind is blowing or even when there is no wind at all.

16. *Osarappe-gawa Bridge ; 50 plate girder.*

The experiments were done on the morning of Oct. 12th 1900. The weather was clear and calm. The girder experimented upon was that next to the Asahigawa side.

Exp. No. 1. Up train; the engine (No. 7) passed over the girder in 2.6s.

Deflection = 10.2mm (measured with the deflectometer).

" = 9.7mm (" " " vibration measurer).

Vert. vib. The max. 2a was 1.0mm, the average period being 0.12s.

Trans. vib. The max. 2a was 4.7mm, the average period being 0.28s. The maximum micro-vibration was 2.2mm.

Long. vib. The max. 2a was 1mm, the period being extremely short.

Exp. No. 2. Down train; the engine (No. 2) passed over the girder in about 3 s. (The vertical instruments were thrown out of the state of stable equilibrium and consequently failed to give the deflection.).

Vert. vib. The max. 2a was about 1mm.

Trans. vib. The max. 2a was 3.3mm, the average period being

0.25s. The maximum motion of the micro-vibrations was 3mm.

Long. vib. The max. 2a was 1.7mm, the period being extremely short.

17. *The 2nd Ishikari-gawa Bridge ; 20' plate girder.* The experiments were done on the after-noon of Oct. 12th 1900. The girder experimented upon was that nearest to the Asahigawa side.

Exp. No. 1. Down train ; Engine No. 1.

Deflection = 5.1mm.

Vert. vib. The max. 2a was about 1mm.

Trans. vib. The max. 2a was 1.6 mm. The average period in the principal portion was 0.11s. The movements in the preliminary portion was regular and distinct and had an average period of 0.10s.

Long. vib. The max. 2a was 2.3mm.

Exp. No. 2. Engine No. 2.

Deflection = 4.9mm.

Vert. vib. The max. 2a was about 1mm.

Trans. vib. The max. 2a was about 2mm, the period being very short.

Long. vib. The max. 2a was 1.7mm.

18. *The 1st Ishikari-gawa Bridge ; double Warren truss through 200'.* The experiments were made on Oct. 13th 1900, the instruments being set up at the middle of the right-hand side bottom chord (looked at from the Asahigawa end).

Exp. No. 1. The engine (No. 1) passed over the girder in 5.0s.

Deflection = 12.4mm.

Vert. vib. The max. 2a was 3.1mm, and the average period in the principal portion was 0.39s ; there being also micro-vibrations. In the preliminary portion, the average period was 0.25s, while in the end. portion it was 0.32s.

Trans. vib. The max. 2a was 3.1mm, the average period in the principal portion being 0.83s. In the preliminary portion there were small vibrations of an average period of 0.23s.

Long. vib. The max. 2a was 1.9mm, the period being very short.

Exp. No. 2. The engine (No. 6) passed over the girder in 5s.

Deflection = 17.1mm.

Vert. vib. The max. 2a was 4.2mm, the average period in the principal portion being 0.37s. The vibrations in the preliminary portion and the end portion were also regular, their average periods being respectively 0.33s and 0.31s.

Trans. vib. The max. 2a was 5.0mm, and the average period in the principal portion was 0.87s; there being some micro-vibrations.

Long. vib. The max. 2a was 1.9mm, the period being extremely short.

Exp. No. 3. 4 men together ran once over the girder, in about 22s.

Vert. vib. The motion was at first *nil* but gradually accumulated to a max. 2a of 1.4 mm, the average period being 0.30s.

Trans. vib. The motion was almost exactly the same as in the following experiment.

Long. vib. *Nil.*

Exp. No. 4. This was the continuation of the preceding experiment, the same 4 men running back over the girder.

Vert. vib. The max. 2a was 1.8mm, the average period being 0.31s.

Trans. vib. The max. 2a was 0.6mm, the average period being 0.75s.

Long. vib. *Nil.*

19. The results of the above experiments are collected in the following table, where the T's of the vertical, transverse and longitudinal vibrations are the average periods of the respective principal movements.

Bridge.
Chubetsu
"
3rd Ishikari
"
"
"
2nd Ishikari
"
"
"
"
"
"
"
Osarappe
"
2nd Ishikari
"
1st Ishikari
"
"
"

* 2a denote

The periods of vibration in the preliminary and end portions of the motion, namely just before and after the passage of the engine or train, are generally a little shorter than in the principal portion. As an example, let us take the first and second experiments on the 1st Ishikari-*gawa* bridge 200′ truss.

TABLE VIII.

THE 1ST ISHIKARI-*GAWA* BRIDGE; 200′ DOUBLE WARREN TRUSS.

No. of expt.	Average period in the		
	Principal portion.	Preliminary portion.	End portion.
1	0.39s	0.25s	0.32s
2	0.37	0.33	9.31
Mean.	0.38	0.29	0.32

Thus the average period in the principal portion was 0.38s, while the mean value of the periods in the preliminary and end portions was smaller by $\frac{1}{5}$ the amount, being equal to 0.30s. This difference is due to the weight of the engines.

Period. Generally, in the movement of a given elastic body, there may exist the fundamental vibration, and its harmonics or those vibrations whose periods are respectively $\frac{1}{2}$, $\frac{1}{3}$, . . . of the latter. The bridge vibrations under consideration seem also to show this phenomenon, for example, as follows.—

TABLE IX.

AVERAGE PERIODS OF THE TRANSVERSE MOTION.

(FUNDAMENTAL AND HARMONIC VIBRATIONS).

Bridge.	Average period of the		
	Principal vibrations.	Small vibrations superposed on the principal.	Vibrations in the prel. or end portion.
Chubetsu 100′	0.53s	0.29s	0.29s
2nd Ishikari 70′ (5th exp.)	0.43	0.20	0.21
Mean	0.48s	0.25s	

In these cases, the period of the harmonic is ½ that of the principal vibrations.

The results contained in Table VII may be summarized as follows.—

Deflection. The greatest deflection of 17.1mm occurred in the case of the 1st Ishikari-*gawa* 200′ double Warren truss, while the smallest value of 4.9mm, occurred in the case of the 2nd Ishikari-*gawa* 20′ plate girder. Excepting, however, the case of the 1st Ishikari-*gawa* bridge, the greatest, deflections occurred in the cases of the plate girders of the 2nd Ishikari-*gawa* (70′) and the Osarappe-*gawa* (50′) bridges. (The deflection of the Chubetsu-*gawa* 60′ plate girder has not been measured.) Thus the mean deflection of the 3rd Ishikari-*gawa* 100′ Pratt truss was 11.6mm, when tried with two heavy tank engines Nos. 6 and 7 joined in series; while the deflection of the similar 100′ Pratt truss of the Chubetsu-*gawa* was, under the engine No. 9, only 8.8mm. On the other hand, the deflection of the 2nd Ishikari-*gawa* 70′ plate girder, due to the engine No. 6 or No. 2, amounted to 11.0 to 11.4mm; while that of the Osarappe-*gawa* 50′ plate girder, due to the engine No. 7, was 10.0mm.

Vertical vibration. The maximum vertical vibration occurred in the case of the 1st Ishikari-*gawa* 200′ truss, its range being 4.2mm. Excepting this bridge, however, the greatest vertical motion occurred in the case of the 2nd Ishikari-*gawa* 70′ plate girder, whose range of motion, under the passage of the engine No. 2 or No. 6, reached 1.5mm; being even greater than the maximum motion of 1.3mm for the 3rd Ishikari-*gawa* 100′ truss, due to the passage of the two engines Nos. 6 and 7 in series. In the cases of the Osarappe-*gawa* 50′ and the 2nd Ishikari-*gawa* 20′ plate girder, the maximum motion was disproportionately great and reached 1mm. The average period of vibration was shortest, namely, 0.12s, in the case of the Osarappe-*gawa* 50′ girder; (that of the 2nd Ishikari-*gawa* 20′ girder was too short to be accurately measured); and longest, namely, 0.38s in the case of the 1st Ishikari-*gawa* 200′ truss. The average periods of the 2nd Ishikari-*gawa* 70′ plate girder and of the 3rd Ishikari-*gawa* 100′ truss were nearly equal to each other, being respectively 0.19s and 0.21s; both of these values, however, differ much from the average period of the Osarappe-*gawa* 50′ girder.

Thus it will be seen that the two similar 100′ Pratt trusses of the Chubetsu-*gawa* and the 3rd Ishikari-*gawa* bridges have smaller deflection and vertical vibration than the 70′ and 50′ plate girders of the 2nd Ishikari-*gawa* and the Osarappe-*gawa* bridges, the period of vibration of the former bridges being shorter than that of the latter. This fact proves that the two 100′ trusses designed by Messrs Tanabe and Eda are sufficiently strong notwithstanding the proportionally smaller mass.

Transverse vibration. The greatest transverse motion of 5.0mm occurred in the case of the 1st Ishikari-*gawa* 200′ truss under the passage of the engine No. 6. The next greatest movement of 4.9mm occurred in the case of the 3rd Ishikari-*gawa* 100′ truss under the passage of the two engines, Nos. 6 and 7, in series. Excepting these two bridges, however, the greatest transverse motion was shown by the 2nd Ishikari-*gawa* 70′ and the Osarappe-*gawa* 50′ plate girders. The average period of vibration was longest in the case of the 1st Ishikari-*gawa* bridge and

shortest in the case of the 2nd Ishikari-*gawa* 20′ girder, being respectively 0.85s and 0.11s.

Longitudinal vibration. The smallest longitudinal motion occurred in the case of the Chubetsu 100′ truss and the first experiment on the 2nd Ishikari-*gawa* 70′ plate girder, being respectively 1.0mm and 0.5mm. In the latter case, the smallness of the motion was probably due to the small number of the cars and the lightness of the engine. In general, the amount of the longitudinal vibration seems to increase with the decrease of the span; the greatest amount of 2.3mm having occurred in the case of the 2nd Ishikari-*gawa* 20′ plate girder. The period of vibration was always very short.

The three component vibrations are small when the trains pass over very slowly, as will be seen from the case of the 3rd Ishikari-*gawa* 100′ truss.

Effect of wind. Bridges of long span execute at all times more or less vibrations, due principally to the effect of winds. Thus, for example, in the 8th experiment on the 2nd Ishikari-*gawa* 70′ girder, there blew moderate winds, which caused slight transverse vibrations; the period of these natural movements was 0.38s, being the same as when a few men ran over the girder.

Effect of a few men running. The 2nd Ishikari-*gawa* 70′ girder showed 0.3mm transverse vibration when two or three men walked slowly over the bridge, the period being 0.38s. (The vertical motion ought of course to have existed, but it was not measured) In the case of the 1st Ishikari-*gawa* 200′ truss, a very remarkable effect was produced by causing four men to run once over the bridge; namely, the maximum vertical vibration thus produced reached 1.8mm, not very different from the motion of 3.1mm produced (in the 1st experiment) by the passage of engine No. 1. The average period of the vertical vibration was 0.31s, or 0.07s shorter than the mean period of 0.38s caused by the trains themselves. The maximum transverse motion of the same 200′ truss, produced by the same 4 men was 0.6mm; the average period being 0.75s,

or about 0.1s shorter than the average period of 0.85s due to the train. In these cases, the longitudinal vibration did not exist.

20. *Kanasugi-gawa Bridge ; 30' Plate Girder Deck.*

This bridge was newly constructed on the Shinbashi and Akabane Railway. The experiments were made on Oct. 25th 1899, when the bridge was opened for the traffic, with a heavy tank engine whose weight was 48 tons. The measurements of the deflection and the vibrations were all made by means of a vibration measurer, there being no necessity for using a deflectometer for bridges of such a short span, which is passed over by an engine in a very short time interval. The results were as follows.

Exp. No. 1. The engine passed over very slowly. (Deflection not measured.)

Vert. vib. The motion consisted of a comparatively slow principal vibrations with very quick micro-vibrations superposed; the max. 2a of these two classes of movements being respectively 0.6mm and 0.8mm. In the end portion, there were vibrations of an average period of 0.053s.

Trans. vib. The max. 2a was 0.9mm. In the principal portion, there were two sets of vibrations whose average periods were respectively 0.22s and 0.10s. Besides these there were very quick micro-vibrations, whose max. motion of 0.9mm occurred after the passage of the engine.

Long. vib. The max. 2a was 0.3mm, the period being very short. In the end portion, there were some trace of vibrations of an average period of 0.057s.

Exp. No. 2. The engine passed over the girder in 1.3s.

Deflection = 6.0mm.

Vert. vib. The max. 2a of the fundamental vibrations was 0.7mm. In the principal portion there were also prominent quick movements, whose max. motion was 1.4mm. In the end portion, the average period was 0.052s.

Trans. vib. The max. 2a was 2.6mm; the average period being 0.20s in the principal portion and 0.11s in the end portion. The max. 2a of the superposed quick-vibrations was 0.4mm.

Long. vib. The max. 2a was 0.7mm, the period being very short.

In the preliminary portion, however, there were small but distinct vibrations of an average period of 0.10s. In the end portion the average period was 0.09s.

Exp. No. 3. The engine passed over the girder in 1.1s.

Deflection = 6.9mm.

Vert. vib. The max. 2a was 0.8mm, the average period being 0.06s in the principal portion, 0.049s in the end portion, and 0.05s in the preliminary portion. There were also small but distinct micro-vibrations of an average period of 0.022s, whose maximum motion was 1.0mm.

Trans. vib. The max. 2a was 2.5mm, the average period in the principal portion, which consisted of distinct vibrations, being 0.10s. The max. 2a of the micro-vibrations was 0.7mm.

The results of the above experiments are summarized in the following table.

TABLE X.

KANASUGI-*GAWA* BRIDGE; DEFLECTION AND VIBRATION.

No. of expt.	Deflection. (mm)	Vertical Vibration.		Transverse Vibration.		Long. Vibration.
		Max. 2a (mm)	T(s)	Max. 2a (mm)	T(s)	Max. 2a (mm)
1	——	0.6(0.8)	0.053	0.9(0.9)	{0.22 / 0.10}	0.3
2	6.0	0.7(1.4)	0.052	2.6(0.4)	0.20	0.7
3	6.9	0.8(1.0)	0.060	2.5(0.8)	0.10	1.2
Mean.	6.5	0.7(1.1)	0.055	2.6* (0.7)	{0.21 / 0.10}	——

* Exp. No. 1. excepted.

The period given in the above table is the average period of the principal vibrations. Further, the *max.* $2a$ means the greatest fundamental vibration in the respective component, the maximum of the superposed quick vibrations being given within brackets. In the case of the transverse motion, there were two kinds of vibrations whose periods were respectively 0.21s and 0.10s.

21. *Ibi-gawa Bridge; Double Warren Truss through 200′.*

The experiments were executed on April 16th 1900, the instruments having been set up on the right-hand side bottom chord of the second 200′ truss (counted from the Tokyo side). The measurement of the deflection by means of the deflectometer was successful only in the cases of the express trains in the 2nd and 7th experiments, when the engines passed over the span each time in 5s. As there was no water beneath the girder experimented upon, Mr. Yoshida of the Railway Department measured the deflections directly by means of wooden beams erected under the bottom chord of the truss at its middle. The results so obtained are also given in Table XII and are marked "checks." The height of the bottom chord above the river bed was about 30′.

The engines and trains were as tabulated next.

TABLE XI.

IBI-*GAWA* BRIDGE EXPERIMENTS; TRAINS AND ENGINES.

No. of experiment.	Train.	No. of train.	No. of engine.	Total weight of engine.	Weight of tender.
1	Up.	246	——	——	——
2	Down.	103	11 (Tank engine.)	t 28.00	——
3	——	(2 men running)	——	——	——
4	Up.	420 (Goods train.)	102 („)	33.43	——
5	——	(Natural vibr.)	——	——	——
6	Up.	106	11 („)	28.00	——
7	Down.	119	83 (Tender engine.)	43.60	t 15.9
8	Up.	247	88 („)	„	„
9	„	108	88 („)	„	„
10	Down.	105	10; (Tank engine.)	23.43	——

The results of the experiments were as follows.

Exp. No. 1.

Deflection $= \frac{11''}{16}$ or 17.5mm. (Measured at the river bed.)

Vert. vib. The max. 2a was 1.4mm and the average period in the principal portion was 0.37s, there being also small quick vibrations of an average period of 0.17s. In the preliminary portion the average period was 0.23s.

Exp. No. 2. The engine passed over the girder in 5s.

Deflection = 18.0mm. (Measured by instrument on the bridge.);

„ $= \frac{5''}{8}$ or 15.9mm. (Measured at the river bed.)

Vert. vib. The max. 2a was 4mm, the average period in the principal portion being 0.27s. In the preliminary portion, when the engine was not yet on the girder, there were already some distinct movements of which the maximum was 1.2mm and whose average period was 0.27s.

Exp. No. 3.

Vert. vib. The max. 2a was 0.5mm, the average period being 0.28s.

Exp. No. 4.

Deflection $= \frac{3''}{4}$ or 19.0mm (measured at the river bed).

Vert. vib. The max. 2a was 2.2mm, the average period in the principal portion being 0.37s. In the preliminary portion, there were two sets of vibrations of average periods respectively of 0.19s and 0.33s.

Trans. vib. In the preliminary portion, the vibrations had a maximum range of 0.2mm and an average period of 0.32s, here and there superposed with quick vibrations of an average period of 0.20s; these different sets of movements being themselves superposed on slow vibrations of an average period of 0.74s. During the 2.3 seconds interval after the entrance of the engine on the girder, the motion consisted entirely of vibrations (max. 2a=1.0mm) of an average period of 0.24s. But thereafter large vibrations became predominating and indicated the max. (absolute) 2a of 4.8mm; and the motion was most active during 6 seconds between the 7th and 13ths after the entrance of the engine on the girder, the average period during that interval being 1.06s. In the end portion the average period was 0.75s.

Long. vib. The record receiver of the vibration measurer was set in motion 17s before the entrance of the engine on the girder; but already then there existed distinct vibrations whose maximum was 0.15mm and whose average period was 0.34s, there being also some quick vibrations. In the principal portion, the average period was 0.30s and the max. 2a of 0.35mm happened 12s after the entrance of the engine on the girder. The max. 2a of the quick vibrations was 0.1mm, their average period being 0.039s.

Exp. No. 5. In this experiment, I have measured the *natural* vibrations of the bridge, not caused by artificial disturbance or by the existence of any appreciable amount of wind.

Trans. vib. The max. 2a was 0.2mm, the average period being 0.72s.

Long. vib. *Nil.*

Exp. No. 6.

Deflection $=\frac{5''}{8}$ or 15.9mm (measured at the river bed).

Vert. vib. The motion existed already at 13.3s before the entrance of the engine on the girder. During this preliminary portion the amplitude remained almost constant (max. 1.0mm), the average period being 0.30s. In the principal portion, the max. 2a was 4.6mm and the average period 0.31s. In the end portion the average period was 0.31s.

Trans. vib. In the preliminary portion the average period was 0.34s. In the earlier part of the principal portion, that is to say, when the engine just came on the girder, the maximum motion was 3.1mm and the average period 0.29s. The absolute max. 2a of 5.8mm, however, occurred a few seconds later on, when the average period was 0.86s.

Long. vib. In the preliminary portion, there werer egular vibrations (max. motion = 0.3mm) of an average period of 0.33s. As the engine approached the girder, there appeared quick vibrations of an average period of 0.041s. The max. 2a in the principal portion was 0.8mm.

Exp. No. 7.

Deflection = 13.3mm (measured instrumentally on the bridge);

,, $=\frac{1''}{2}$ or 12.7mm (measured at the river bed).

Vert. vib. The max. 2a was 4.5mm, the average period being 0.39s in the principal portion and 0.41s in the end portion.

Trans. vib. In the preliminary portion, when the engine was not yet on the girder, there were small movements of an average period of 0.36s; but as the engine came on the girder, the motion consisted at first almost entirely of vibrations of an average period of 0.20s. After 1.3s,

there appeared regular slow vibrations, whose max. 2a was 5.3mm and whose average period was 0.86s. In the end portion, the motion was also regular and had an average period of 0.74s. In the preliminary portion, there were distinct quick vibrations (max. motion = 0.2mm) of an average period of 0.034s.

Long. vib. In the preliminary portion, there were comparatively slow small vibrations of an average period of 0.35s. In the principal portion, the motion consisted of similar vibrations (max. 2a = 0.7mm), the average period being 0.37s. On these movements were superposed quick vibrations of an average period of 0.033s.

Exp. No. 8.

Deflection $= \frac{9''}{16}$ or 14.3mm (measured at the river bed).

Vert. vib. The max. 2a was 2mm, the average period being 0.36s in the principal portion and 0.38s in the end portion. Towards the end of the principal portion, however, there were vibrations of an average period of 0.18s; at the commencement of the same portion there were quick vibrations of an average period of 0.034s.

Trans. vib. The max. 2a was 7.3mm, the average period being 0.98s in the principal portion and 0.72s in the end portion.

Long. vib. In the preliminary portion there were small movements of an average period of 0.33s.

Exp. No. 9. The engine passed over the girder in about 7s.

Deflection $= \frac{1''}{2}$ or 12.7mm (measured at the river bed).

Vert. vib. The max. 2a was 2.2mm. The motion in the principal portion consisted chiefly of vibrations of an average period of 0.42s mixed up with those of an average period of 0.22s. In the preliminary portion, the average period was 0.27s.

Trans. vib. The motion already existed at 20s before the entrance of the engine on the girder, when the record-receiver of the apparatus was started; the average period in this preliminary portion being 0.73s. As the engine entered on the girder, the motion consisted, for the first

2.7s, almost entirely of the vibrations (max. = 1.4mm) of an average period of 0.19s. Thereafter appeared well defined slow vibrations, of which the max. 2a was 4.0mm and average period 0.80s in the principal portion and 0.75s in the end portion. At the 39th second after the entrance of the engine on the girder, when the record-receiver of the apparatus was stopped, the motion was still well defined and had a range of 0.7mm.

Long. vib. In the preliminary portion the max. motion was 0.15mm and the average period 0.30s; the average period of the superposed quick vibrations being 0.18s. In the principal portion the max. 2a was 0.2mm.

Exp. No. 10.

Deflection $= \frac{7''}{16}$ or 11.1mm (measured at the river bed).

Vert. vib. The max. 2a was 1.0mm and the average period 0.27s.

Trans. vib. When the engine just entered on the girder, the average period was 0.57s, the maximum motion being then 3.3mm. The principal portion first began 13s thereafter, the max. 2a being 4.7mm and the average period 0.85s. In the end portion the average period was 0.74s. In the preliminary portion, there were also quick vibrations of an average period of 0.18s.

Long. vib. The amplitude of the comparatively slow vibrations was small. The superposed quick vibrations were, however, prominent, the max. 2a being 0.2mm.

TABLE XII.

IBI-*GAWA* BRIDGE: DEFLECTION AND VIBRATION.

No. of experiment.	Deflection.		Vertical Vibration.		Transverse Vibration.		Longitudinal Vibration.	
	Deflectometer.	"Check"†	2a(mm)	T (s)	2a(mm)	T (s)	2a(mm)	T (s)
		mm						
1	—	$\frac{11''}{16}=17.5$	1.4	0.37	—	—	—	—
2	mm 18	$\frac{5''}{8}=15.9$	4.0	0.27	—	—	—	—
3	—	——	0.5	0.28	—	—	—	—
4	—	$\frac{3''}{4}=19.0$	2.2	0.37	4,8	1.06	0.35	0.30
5	—	——	—	—	0.2	0.72	—	—
6	—	$\frac{5''}{8}=15.9$	4.6	0.31	5.8	0.86	0.8	0.33
7	13.3	$\frac{1''}{2}=12.7$	4.5	0.39	5.3	0.86	0.7	0.37
8	—	$\frac{9''}{16}=14.3$	2.0	0.36	7.3	0.98	—	0.33
9	—	$\frac{1''}{2}=12.7$	2.2	0.42	4.0	0.80	0.2	0.30
10	—	$\frac{7''}{16}=11.1$	1.0	0.27	4.6	0.85	Small	—
Mean.*	—	——	—	0.36	—	0.91	—	0.33

The results contained in the above table may be summarized as follows.

Deflection. The deflections determined with the instrument set up on the girder itself, in expt. Nos 2 and 7, are approximately equal to those directly measured. The maximum deflection of $\frac{3''}{4}$ or 19.0mm occurred in expt. No. 4 (engine No. 102), while the minimum deflection of $\frac{7''}{16}$ or 11.1mm occurred in expt. No. 10 (engine No. 106). It is, however, to be

† The "checks" were originally measured with an inch scale.

* For the vertical vibration, expt. No. 3 is excluded in the deduction of the *mean*; similarly, for the transverse vibration, exp. No. 5 is excluded.

remarked that engines Nos. 102 and 106 were exactly similar to each other, both being tank engines of weight 33.43 tons. Again the deflection was $\frac{5''}{8}$ or 15.9mm in expt. Nos. 2 and 6, the engine being in each case No. 11, a tank engine of weight 28.00 tons. On the other hand, in expt. Nos. 7, 8 and 9, the deflection was slightly smaller and varied from $\frac{1''}{2}$ or 12.7mm to $\frac{9''}{16}$ or 14.3mm; the engines in these experiments being Nos. 83 and 88, which were each a tender engine of weight 43.60 tons. These examples show that the deflection may not always be simply proportional to the weight of the engine in working order.

Vertical vibration. The maximum vertical motion varied in the different experiments between 4.6 mm and 1.0 mm. The average period in the principal portion varied between 0.27s and 0.42s, giving a mean value of 0.36s.

Transverse motion. (Expt. Nos. 3 and 5 excepted.) The maximum transverse motion varied in the different experiments between 7.3 mm and 4.0 mm. The average period in the principal portion varied between 0.80s and 1.06s, giving a mean value of 0.91s.

Longitudinal vibration. The maximum longitudinal motion was 0.8mm; the average period of the slow movements (*pier* motion) being 0.33s.

What has been said above relates to the vibrations in the principal portion. In the case of the vertical and the transverse components, however, the period in the preliminary and end portion is generally a little shorter than that in the principal portion, as will be seen from the following table.

TABLE XIII.

IBI-*GAWA*. BRIDGE EXPERIMENTS. (*Cont.*)

No. of experiment.	Average period in the preliminary or end portion.	
	Vertical Vibration.	Transverse Vibration.
1	0.23 sec.	——
2	0.27	——
4	0.33 0.19	0.75 0.32
6	0.31	0.34
7	0.41	0.74 0.36
8	0.38 0.18	0.72
9	0.27	0.74
10	——	0.74
Mean.	0.31 0.19	0.74 0.34

Thus the principal average period in the preliminary or end portion was 0.31s for the vertical vibration and 0.74s for the transverse vibration, both being smaller than the corresponding mean values given in Table XII. In some of the cases, there were in the vertical component the vibration of an average period of 0.19s, and in the horizontal component those of an average period of 0.34s. In expts Nos. 3 and 5, in which the girder was moving by itself or caused to move by a few men running over it, the periods were nearly equal to those givin in Table XII. In expts Nos. 6, 7 and 9, the vibrations of periods 0.18s to 0.29s (mean = 0.23s) occurred at the entrance of the engines on the girder; the principal large movements appearing a few seconds later on.

22. *Kizu-gawa Bridge; Skew Pratt Truss through 200'.*
The bridge, which spans over the Kizu-*gawa* in the vicinity of the Kasagi Sttaion, stands on piers about 70' high. (It would be interesting to measure also the vibration of the piers themselves.)

The measurement of the deflection and the vertical vibration was made on April 15th 1900 by means of a deflectometer, which was set up at the middle of the up-stream side bottom chord of the truss.

The experiments were made in four ways as follows; *1st expt.*, an express down-train, engine No. 36; *2nd expt.*, a goods train; *3rd expt.*, an express down-train, with engine No. 39 at the head and engine No. 3 at the end; *4th expt.*, two men running together over the girder from one end to the other and then back again. The two engines Nos. 36 and 39 were alike, each being a tender engine whose total weight is 64 tons and the weight of whose tender is 23.50 tons. Engine No. 3 was a tank engine weighing 36.15 tons. In the 3rd experiment, the time interval between the passages of the two engines was 11s. The deflection was successfully measured in the cases of the express trains, namely, in the 1st and 3rd experiments. (Pl. VII gives the diagrams obtained in these two experiments.)

The results were as follows.

Exp. No. 1.

Deflection = 15.2mm.

Vert. vib. The max. 2a was 4.6mm, the principal portion consisting of well defined vibrations of an average period of 0.40s, almost perfectly free from superposition of quick vibrations. In the end portion the vibrations whose average period was 0.19s, were superposed more or less distinctly on slow movements of an average period of 0.43s. The average period in the preliminary portion was 0.18s.

Expt. No. 2. (The measurement of deflection was unsatisfactory, as the record receiver of the apparatus was started a little too late.)

Vert. vib. The max. 2a was 5.2mm, the average period in the principal portion being 0.37s.

Exp. No. 3.

Deflection = 16.8mm, due to engine No. 39. The deflection due to engine No. 3, which passed over 11s after the first, was not satisfactorily registered but was certainly less than the amount here given.

Vert. vib. The max. 2a due to engine No. 39 was 4.2mm, the

average period in the corresponding principal portion being 0.33s; while the max. 2a due to engine No. 3 was 2.5mm, the average period in the corresponding principal portion being 0.42s. The motion was still active during 6s after the passage of the end engine and had an average period of 0.30s. The record-receiver was stopped 14s further on, but the motion was then still well defined; the average period in the end portion being 0.32s. The motion consisted of regular vibrations, almost perfectly free from the superposition of micro-vibrations.

Expt. No. 4.

Vert. vib. The max. 2a was 1.8mm, the average period being 0.32s in the principal portion and 0.30s in the end portion.

The following table gives a summary of the results of the above experiments.

TABLE XIV.

KIZU-*GAWA* BRIDGE EXPERIMENTS; DEFLECTION AND VERTICAL VIBRATION.

No of. experiment.	Deflection. (mm.)	Vertical Vibration.		
		Max. 2a (mm)	Aver. per. in the principal portion.	Aver. per. in the preliminary. or end portion.
1	15.2	4.6	0.40s	0.43s 0.19
2	——	5.2	0.37	——
3	16.8	4.2	0.38	0.31
4	——	1.8	0.32	0.30
Mean.	16.0	—	0.38*	0.37* 0.19

* Exp. No. 4 excluded.

The average period in the principal portion was 0.38s, while that of the natural vibrations, due to the running of two men, was 0.31s.

23. *Summary of results.* It is my intention in future to reduce somewhat the size of the instruments and thus render the apparatus still more convenient for practical working. A general discussion of the movements of railway bridges is reserved for another occasion when the measurements of many other bridges have been obtained. We can, however, at present discuss some important consequences from the experiments so for completed. Thus, the 50′ and 70′ plate girders of the Osarappe-*gawa* and the 2nd Ishikari-*gawa* bridges have shown nearly equal amounts of deflection and also of vertical, transverse and longitudinal vibrations as the 100′ Pratt trusses of the Chubetsu-*gawa* and the 3rd Ishikari-*gawa* bridges; in some cases the amounts have been even greater in the two first named than in the two last named. This shows that these plate girders are comparatively weak and not constructed in accordance with sufficiently accurate mechanical principles. The large amount of the vibratory movements of a plate girder deck may be partly due to the fact that the trains pass over it and cause it to vibrate as an inverted pendulum. In the case of a truss girder through, on the other hand, such an effect would be small.

The deflection and vibration experiments furnish us criterions of the quality of an iron bridge or other structure, deflection being the test of strength and vibration that of rigidity. The high rigidity of an iron bridge is, I believe, defined by the smallness of amplitude and the shortness of period, of the vibratory movements.

The remarkably large amount of vertical vibration produced by causing 2 to 4 men to run together over the 200′ girders of the 1st Ishikari-*gawa* and the Kizu-*gawa* bridges is a very good illustration of the accumulation of motion of an elastic body, when the cause of disturbance is continued sufficiently long, the movements being in these cases the natural or proper elastic vibrations of the bridge girders. This fact explains why a bridge sometimes gives way and breaks when many people are gathered on it, although initially found good when tested with

a stationary load; the continually moving mass leading to an accumulation of the vertical vibrations.

The vibrations of bridge girders, due to the passage of railway trains are also their proper movements, that is to say, they have for a given load a period or periods of motion approximately constant for each of them; the period therefore does not depend on the velocity of the locomotives or on the distances between the wheels of the cars. The effect of the engine is to prolong the period by a small amount; in the cases, for instance, of the vertical vibration of the 200′ trusses of the 1st Ishikari-*gawa*, the Ibi-*gawa* and the Kizu-*gawa*, this increase of period varied between 0.08s and 0.14s, the period of the natural vibrations of these trusses being from 0.28s to 0.32s; the weight of the engines in these experiments varied from 43.6 tons to 64.0 tons.

The following table, which has been constructed from the tables already given, embodies the maximum and mean values of the deflections as well as the elements of motion of the three component movements. In deducing the figures in the table, the natural vibrations, or those caused by winds, etc., have not been included. Further, the *mean max.* $2a$ denotes the mean value of the maximum ranges of motion in the different determinations relating to a given bridge, while the *absolute max.* $2a$ is the greatest among these various maxima; and similarly the *mean* T denotes the mean value of the average periods of the principal vibrations, *max.* T being the longest one among these. The numbers in the horizontal lines marked with *asterisks* (*) in this table as well as in Table XVI are those which represent, or may be regarded as representing, the cases of the application of the maximum load.

Relation between the span and the deflection and vibration. The following remarks on the relation between the span and the deflection and vibration are based on the foregoing table, Figs. 4 to 10 giving the graphical illustrations.

Deflection. The following table gives the ratio of deflection and span of the different bridge girders, expressed in fractions and decimals.

TABLE XVI.

AMOUNT OF THE BRIDGE DEFLECTIONS.

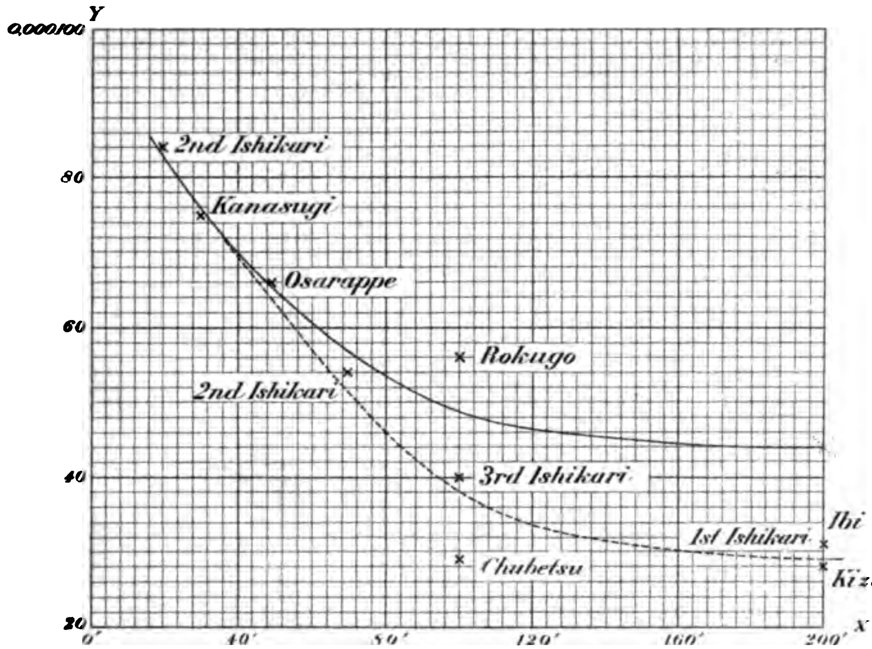
Bridge.	Ratio of maximum deflection to span length.	
	(in fraction.)	(in decimal.)
Rokugo,* 100′	$\frac{1}{1780}$	0.00056
Chubetsu, 100′	$\frac{1}{3460}$	0.00029
3rd Ishikari,* 100′	$\frac{1}{2530}$	0.00040
2nd Ishikari, 70′	$\frac{1}{1870}$	0.00054
Osarappe,* 50′	$\frac{1}{1520}$	0.00066
2nd Ishikari,* 20′	$\frac{1}{1190}$	0.00084
1st Ishikari, 200′	$\frac{1}{3560}$	0.00028
Kanasugi,* 30′	$\frac{1}{1330}$	0.00075
Ibi, 200′	$\frac{1}{3210}$	0.00031
Kiso, 200′	$\frac{1}{3630}$	0.00028

* Cases of heaviest load.

The ratio of deflection to span of the different bridges, expressed in fractions, thus varies between $\frac{1}{3000}$ (min.) for the 200′ trusses and $\frac{1}{1190}$ (max.) for the 20′ plate girder of the 2nd Ishikari-*gawa* bridge. If the allowable amount of the deflection be, as adopted by the Imperial Railway Bureau, fixed at $\frac{1}{900}$, all the bridges examined so far are within the safety limit. Even in the case of the Rokugo-*gawa* bridge, the maximum, or full load, deflection in the present state of the traffic does not exceed $\frac{1}{1780}$. In Fig. 4, which illustrates the relation between the span and the ratio of the deflection to the latter, expressed in decimals, the points (⊗) indicate the cases in which the engines in the experiments were not the heaviest that may pass over the bridges in question. In the cases of the three 200′ trusses of the 1st Ishikari-*gawa*, the Ibi-*gawa* and the Kizu-*gawa* bridges which were of this nature, I take provisionally for the ratio corresponding to case of the full load, the value of 0.00045, obtained by increasing by 50% the mean deflection of the three bridges. (This is represented by the point *B*.) Now the different bridge girders are of different construction and consequently their strengths are not simply proportional to the deflections. For illustrating the general relation of the span and deflection, however, I have drawn the two curves (I) and (II), connecting the different points, where (I) represents the cases when the load was the heaviest possible, and (II) those when the load was that in the ordinary daily traffic. From these curves it will be seen that the ratio of the deflection of the 200′ trusses amounts to only $\frac{1}{2}$ or $\frac{1}{3}$ of that of the 20′-70′ plate girders. Again the amount of deflection of these latter girders was disproportionally large while that of the 3rd Ishikari-*gawa* and the Chubetsu-*gawa* 100′ trusses was very small. In Fig. 5, which illustrates the relation between the actual amount of the deflection (expressed in mm) and the span, the curve represents the condition in the actual traffic, the sign (⊗) having the same signification as in Fig. 4.

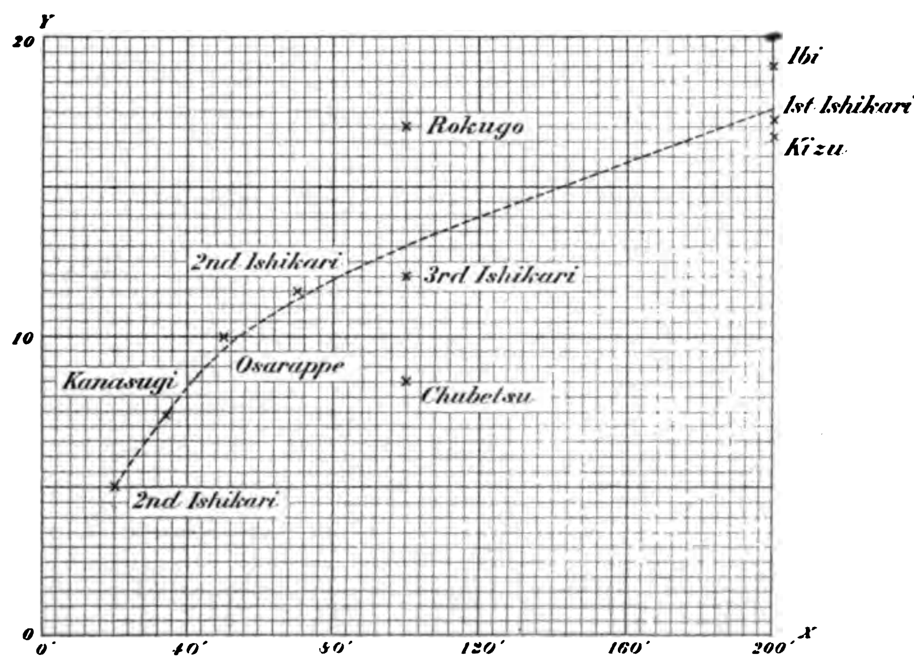
Vertical vibration. Fig. 6 illustrates the relation between the span and the (abs.) maximum vertical motion. Excepting the Rokugo-*gawa* bridge, the three 200′ trusses of the 1st Ishikari, the Ibi and the Kizu bridges gave a mean vertical vibration of 4.7mm, which is much

Fig. 4. Relation between Span Length and Deflection.



X = Span length.
Y = Ratio of max. deflection to span length.

Fig. 5. Relation between Span Length and Deflection.



X = Span length.
Y = Max. deflection.

larger than the corresponding quantity of the other 6 bridges, whose girders vary between 20′ and 100′ in length. The large amount of the vertical motion in the cases of the 200′ trusses is probably due, in part, to the phenomenon of the accumulation of motion, as explained before.

Fig. 7 illustrates the relation between the (abs.) maximum period of the vertical motion and the span. It will be seen that the former increases more rapidly than the latter.

Transverse vibration. Fig. 8 illustrates the relation between the span and the (abs.) maximum transverse motion. The movement of the 200′ trusses was greater than that of the shorter girders; but the difference between the two groups was in this case not so marked as with the vertical vibration. Fig. 9 illustrates the relation between the (abs.) maximum period of the transverse motion and the span, the former increasing less rapidly than the latter.

In Figs. 4 to 9, I have taken the absolutely greatest values of the range of motion and of period. Nearly similar curves are obtained if we take the mean values instead of the absolute maxima.

Longitudinal vibration. The maximum longitudinal motion of 2.3mm took place in the case of the 2nd Ishikari-*gawa* 20′ plate girder, while the minimum motion of 0.8mm took place in the case of the Ibi-*gawa* 200′ truss. As will be seen from Fig. 10, the longitudinal motion appears to increase with the diminution of the span. Part of this component motion probably arises from the vibration of the piers themselves.

24. *Comparison of bridge vibrations with the macro-seismic motion.* I give here a comparison of the bridge vibrations with the macro-seismic motion. For the results of the recent earthquake measurement, the reader is referred to the *Publications*, No. 4; *Report* (Japanese), Vol. XXXII; and Jour. Sc. Coll., Imp. Univ., Tokyo, Vols. II and XI, from which the following notes are taken.

In the great Mino-Owari earthquake of Oct. 28th 1891, the maximum horizontal motion at Nagoya, estimated from various overturned columns, was about 210mm, the period being probably about 1.3s.

In the great Tokyo earthquake of June 20th 1894, the strong motion

seismograph at the Seismological Institute recorded the maximum horizontal motion of 73mm, the period being 1.8s. The maximum vertical motion was 10mm.

Miyako observation. During the 2 years between June 1896 and June 1898, the Gray-Milne type seismograph at the Meteorological Observatory of Miyako recorded 31 earthquakes, of which 8 were *strong*, and the rest were all *weak* or *slight*. The period of the maximum horizontal motion varied between 0.53s and 1.7s. To give examples of the range of motion, I take the earthquake of Aug. 31st 1896, at 4.12.48 p.m., which was one of the fore-shocks of the great Riku-U earthquake: in this case, the maximum horizontal motion was 9.0mm (period 0.94s), while the maximum vertical motion was 1.3mm (period 0.9s).

Kyoto observation. During about 5¼ years between January 1895 and March 1900, there were observed instrumentally at the Kyoto Meteorological Observatory 48 earthquakes, of which 2 were *strong* and the rest all *weak* or *slight*. The average period of the principal vibrations in the horizontal component was 0.9s.

Tokyo observation. According to the late Prof. S. Sekiya, who measured 119 earthquakes in Tokyo during the two years between Sept. 1885 and Aug. 1887, the average maximum horizontal motion was 1.2mm at Hitotsubashi and 0.37mm at Hongo, the corresponding mean period at these two stations being respectively 1.0s and 0.76s. The vertical motion was in each case much smaller than the horizontal.

According to what has been stated above it will be seen that in *weak* and *slight* earthquakes the maximum range of motion amounts only to about 1mm. When it reaches some 10mm, the earthquake is to be regarded as being *strong*, while with a movement of 1 or 2 inches, considerable damage will be produced to brick buildings, chimneys, etc. If the motion reaches some 5 inches, we have a case of a great destructive earthquake. The average period of the principal vibration is in small earthquakes about 1s, while in *strong* and destructive earthquakes it is generally between 1 and 2s, there being in these latter cases also *ripples* or small quick vibrations.

I shall next compare the bridge vibration with the macro-seismic motion.

The vertical vibration of bridge girders is much greater than in *strong* or *weak* earthquakes. The following tables give a comparison of the mean values of the vibration of the three 200′ trusses of the 1st Ishikari, the Ibi and the Kizu-*gawa* bridges with the earthquake of June 20th 1894 observed at Hongo (Tokyo); Table XVII referring to the vertical and Table XVIII to the horizontal component.

TABLE XVII.

VERTICAL MOTION.

Bridge, eqke.	Max. 2a. (mm)	Period of max. 2a (s)	Max. vel. (mm/s)	Max. acc. (mm/s²)
200′ trusses of 1st Ishikari, Ibi and Kizu. (*mean values.*)	4.7	0.4	37.0	58.0
Tokyo eqke of June 20, 1894, (Hongo.)	10.0	1.8	17.4	61.0
Eqke of Aug. 31, 1896, (Miyako.)	1.3	0.9	4.5	32.0

TABLE XVIII.

HORIZONTAL MOTION AND TRANSVERSE VIBRATION.

Bridge, eqke.	Max. 2a. (mm)	Period of max. 2a. (s)	Max. vel. (mm/s)	Max. acc. (mm/s²).
200′ trusses of 1st Ishikari, Ibi and Kizu. (*mean values.*)	6.2	0.97	20.1	130.0
Tokyo eqke of June 20, 1894, (Hongo).	73.0	1.8	127.0	444.0
Eqke of Aug. 31, 1896, (Miyako)	9.0	0.94	30.0	20.0

Finally the following table gives the elements of vibration of the Ro kugo-*gawa* and the other seven bridge girders of spans less than 100′.

TABLE XIX.

VIBRATION OF BRIDGES OF SPANS 100′-20′.

Bridge.		Max. 2a (mm)	Period. (s)	Max. vel. (mm/s)	Max. acc. (mm/s²)
I. Vertical Vibration.					
Rokugo,	100′	3.7	0.25	46.5	1170
Chubetsu,	60′	—	—	—	—
”	100′	1.2	0.25	15.0	379
3rd Ishikari,	100′	1.4	0.22	20.0	572
2nd Ishikari,	70′	1.5	0.19	24.7	822
Osarappe,	50′	1.0	0.12	26.1	1370
2nd Ishikari,	20′	1.0	—	—	—
Kanasugi,	30′	0.8	0.06	41.8	4400
II. Transverse Vibration.					
Rokugo,	100′	10.5	0.64	51.5	505
Chubetsu,	60′	3.8	0.30	39.7	834
”	100′	3.3	0.53	19.5	232
3rd Ishikari,	100′	4.9	0.51	30.1	372
2nd Ishikari,	70′	4.4	0.43	32.0	468
Osarappe,	50′	4.7	0.28	52.6	1180
2nd Ishikari,	20′	2.0	0.11	57.0	3260
Kanasugi,	30′	2.6	0.22	37.0	1060

The above three tables give a comparison of the bridge vibrations with the earthquake motion, in regard to magnitude and intensity. The bridge vibrations, though in no way equal to the movements in great destructive earthquakes, reach sometimes the strength of motion in *strong* earthquakes. As, moreover, the bridge vibrations are very quick in period, their acceleration is in many cases markedly greater than that of the earthquake motion.

25. *Remarks on Table XV.* From Table XV, it will be seen that the deflection as well as the vertical and the transverse vibrations of the Rokugo-*gawa* 100′ Warren truss are much greater than those of the 100′ Pratt trusses of the two Hokkaido bridges; the period of the transverse

motion being also significantly longer for the former bridge than for the two latter. It may also be noticed that small plate girders, such as the Osarappe 50′, the 2nd Ishikari 20′ and the Kanasugi 30′ girders, are always subject to disproportionately large stresses.

That a weak bridge girder has a slow period of oscillation is well illustrated by the transverse vibrations of the 200′ trusses of the 1st Ishikari-*gawa* and the Ibi-*gawa* bridges. Thus the maximum length of the period was 1.06s for the Ibi-*gawa* and 0.87s for the 1st Ishikari-*gawa* bridge; accordingly, we find the maximum motion of 7.3mm for the former bridge and the maximum of 5.0mm for the latter.

To illustrate the relation between the strength of a given structure and the period of its vibration, suppose that there are two iron bridge girders, *A* and *B*, of exactly the same length and construction. If now the rivetting of *A* is perfect, while that of *B* is not so, then the girders may be looked upon as two elastic systems of equal mass, whose elastic moduli are, however, unequal, *A* being more rigid than *B*. Consequently the girder *B* ought to have a longer period and be capable of being thrown into movements of greater amplitude, than the girder *B*. This consideration serves to show that it may be possible to detect imperfections, in the construction of a bridge girder from a careful study of its vibrations.

The maximum range of the vertical vibration varies with the deflection though not simply proportional to it. Thus; the four bridges of the Rokugo, the 1st Ishikari, the Ibi and the Kizu *gawa* have large deflections, which vary between 16.8mm and 19.0mm and whose mean value is 17.5mm; while the maximum ranges of their vertical vibration vary between 3.7mm and 5.2mm, giving a mean of 4.4mm. On the other hand, the remaining six girders (with the exception of the Chubetsu bridge 60′ girder, the deflection and vertical vibration of which were not measured) have small deflections, which vary between 5.1mm and 12.0mm with a mean value of 9.0mm, their maximum vertical vibrations varying between 0.8mm and 1.5mm, with a mean value of 1.2mm. The measurement of the vertical vibration therefore also furnishes us with a test on the strength of a given bridge girder.

The vertical and the transverse vibrations of the different bridges as given in Table XV are much more violent, that is to say, they have far greater accelerations, than the movement in ordinary *weak* and *strong* earthquakes. (See § 24.) The transverse vibrations, though having little connection with the vertical strength of the girder, must be duly considered as it is likely that strong winds would much augment them. During the violent storm on Oct. 7th 1899* in Japan, a railway train of the Nippon Railway Company was, while running over the Hoki-*gawa* bridge in the province of Shimotsuke, upset and several passenger cars were thrown down into the river, causing a considerable loss of life. In this case, the overturning of the cars was of course due to the direct action of the wind. But I believe the horizontal vibrations of the bridge, which consists of a series of 70′ plate girders, must have been not insignificant, and these might, on account of their great accelerations, help to increase the shaking of the cars themselves, thus favouring the condition of overturning of the latter.

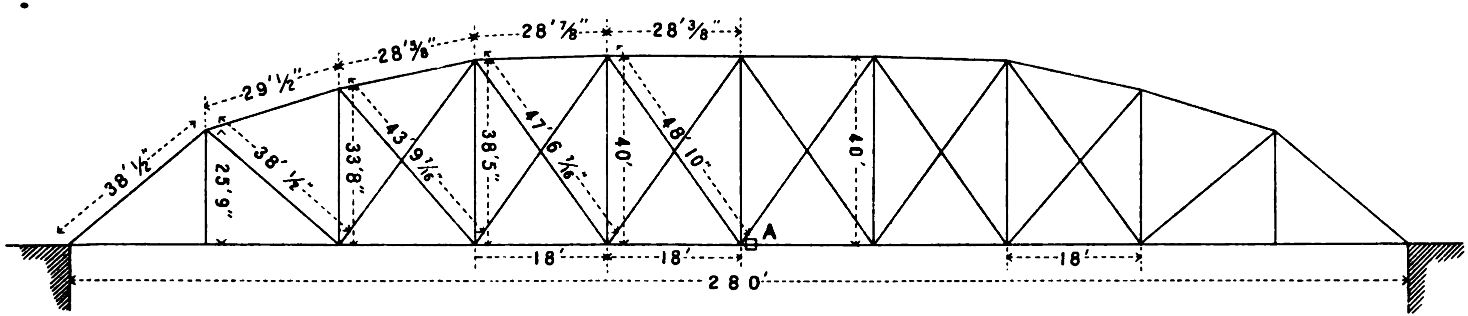
Recently the question has been discussed among railway engineers whether the overturning of railway wagons by the force of wind be different when the train is running quickly and when it is at rest. According to the present series of experiments it seems probable that there must exist some theoretical difference between the two cases. Thus, when the train is at rest, the ground and the rails are still ; but when the train is running quickly, say, when passeng over a bridge, the latter is thrown into its own vibrations, which may tend to co-operate with winds in overturning the wagons.

APPENDIX.

26. *Hozu-gawa Bridge; 280′ Bow String Truss.* On Dec. 10th 1900, Messrs Tanabe and Hibi of the Kyoto Imperial University, measured, with the vibration measurer described in § 4, the vibrations of the 280′ bow string truss of the Hozu-*gawa* bridge on the Kyoto Railway. The

* This storm caused sea-waves along almost the whole coast of Japan, and great devastation in the Suruga Bay.

Fig. 11. Hozu-gawa Bridge 280′ Bow String Truss, Kyoto Railway.



following is the translation of a note by Messrs Tanabe and Hibi.—

"The Hȯzu-*gawa* bridge is about 2 miles from the Saga Station and has a clear span of 280′, being the longest which exists in Japan. The panel length is 18′ and the distance between the two trusses is 16′; the total weight of the girder being 453.900 lbs. The girder was manufactured by the Pencoid Co., and has vertical as well as horizontal bracings· The mass of the girder is compratively small, the weight per sq. ft being 1620 lbs.

"During the experiments the weather was fine, but strongly windy. The vibrations caused by the wind seemed, however, to be very slight. The measurement was repeated four times, the 4th being that of the effect caused by 5 men running over the girder.

"Exp. No. 1. Up train; 10.30 a.m. The engine passed over the girder in 10.4s, that is to say, with a velocity of about 19 miles per hour. The train consisted of engine No. 4--three goods wagons--break van—one goods car--eight passenger wagons.

"Exp. No. 2. Up train; 0.20 p.m. The engine passed over the girder in 7.4s, or with a velocity of about 25.9 miles per hour. The train consisted of engine No. 5--nine goods wagons--break van--one goods wagons--nine passenger wagons.

"Exp. No. 3. Down train; 0.35 p.m. The engine passed over the girder in 7.8s or with a velocity of about 24.5 miles per hour. The train consisted of engine No. 4--five goods wagons--eight passenger wagons--one goods wagon--break van.

"The experiments were carried on by setting up the instrument on the *refuge* at the middle of the span. The engines Nos. 4 and 5 are similar tender engines, each weighing 47.83 tons, of which the tender weighs 16 tons. The gross weight of a passenger wagon may on average be taken at about 5 tons and that of a goods wagon at about 3.5 tons. In the 3rd experiment, all the goods wagons were empty, the weight of such a wagon being about 4500 lbs. Dec. 9th 1900. S. Tanabe and T. Hibi."

The following is a summary of the analysis of the diagrams obtained by Messrs Tanabe and Hibi.

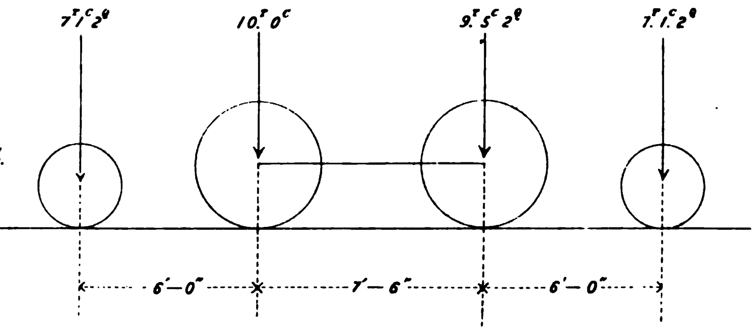
第十七版 Pl. XVII.

(六郷川橋試驗) 明治三十二年十月廿五日
及ビ三十三年二月五日 官設鐵道滊關車

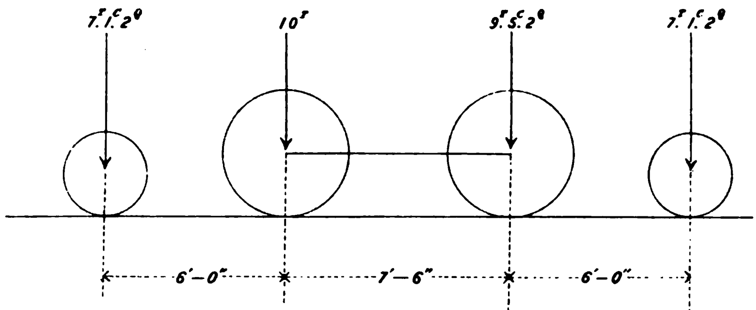
(The Rokugo-gawa Bridge Experiments. Oct. 25th, 1899 and Feb. 5th, 1900.)

Gov. Railway Engines.

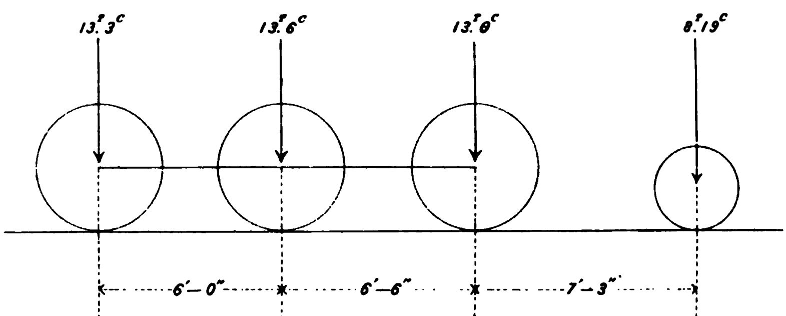
Nos. 61, 62, 91, 114.
Tank engine.
タンク滊關車



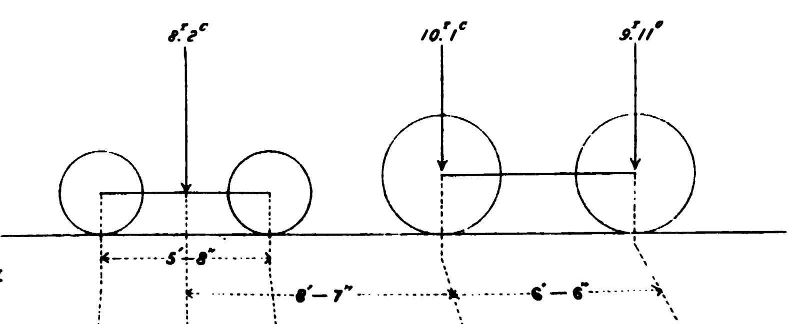
Nos. 98, 70.
Tank engine
タンク滊關車



Nos. 109, 111.
Tank engine
タンク滊關車



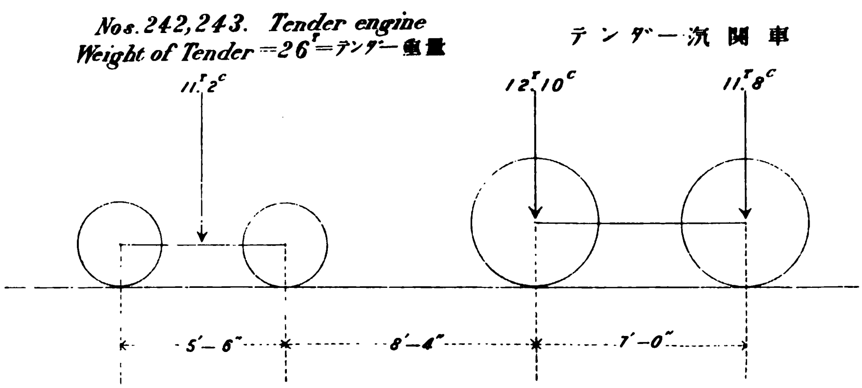
Nos. 119, 205.
Tender engine
テンダー滊關車
{*Wt. of tender*
=21T=テンダー重量



〔六郷川橋試驗〕明治三十二年十月廿五日續キ 官設鐵道汽關車

(The Rokugo-gawa Bridge Experiments. Oct. 25th 1899, (cont.))

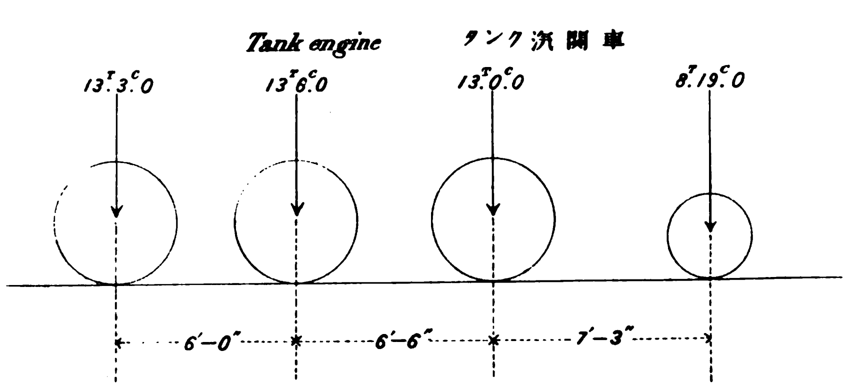
Gov. Railway Engines.



〔金杉川橋試驗〕官設鐵道汽關車

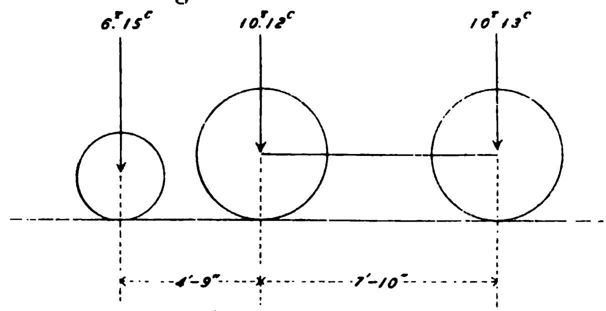
(Kanasugi-gawa Bridge Experiments)

Gov. Railway Engine.

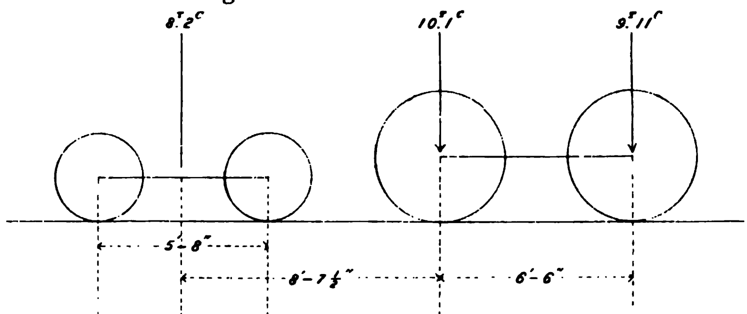


(Ibi-gawa Bridge Experiments.) Gov. Railway Engines.

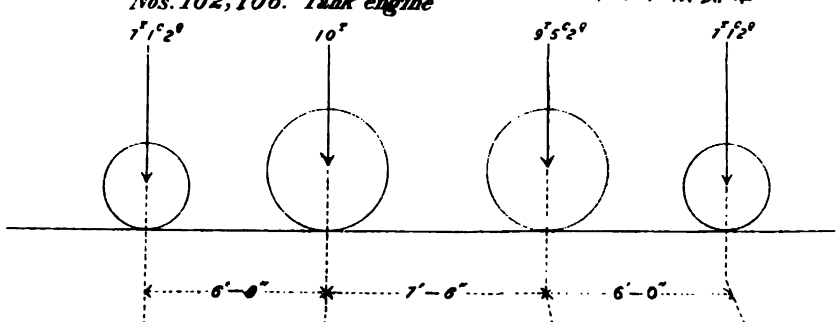
No. 11. Tank engine. タンク汽關車



Nos. 83, 88. Tender engine. テンダー汽關車
Weight of tender = 15T 18C = テンダー重量



Nos. 102, 106. Tank engine タンク汽關車



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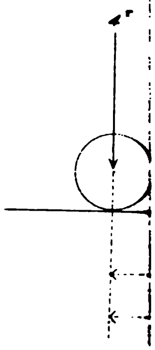

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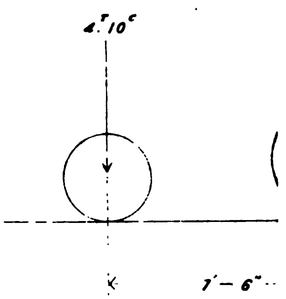

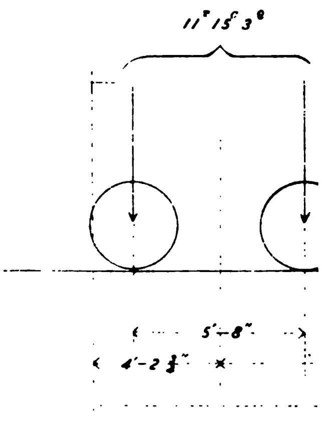

印刷所　三秀舍活版所
東京市神田區美土代町二丁目一番地

印刷者　島連太郎
東京市神田區美土代町二丁目一番地

震災豫防調査會

明治三十五年四月廿八日發行

明治三十五年三月廿五日印刷

On the Deflection and Vibration of Railway Bridges.

by

F. Omori.

PUBLICATIONS

OF THE

Earthquake Investigation Committee

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FOREIGN LANGUAGES.

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MACRO-SEISMIC MEASUREMENT IN TOKYO. I.

BY

F. OMORI, D. Sc.,

Member of the Imperial Earthquake Investigation Committee.

Introduction.

The present volume, which may be regarded as the continuation of the late Professor S. Sekiya's paper on the Tokyo earthquake measurement,* contains the analysis of the diagrams of the 220 earthquakes observed, with the exception of the first nine, between Sept. 1887 and July 1889, at three places in Tokyo, as follows:

Observing station.	Number of earthquakes observed.	Position of observing station.	
		Latitude, *N.*	Longitude, *E.*
Hongo (Seismological Institute.)	82	35° 42′ 29″	139° 45′ 53″
Hitotsubashi.	78	35° 41′ 17″	139° 45′ 35″
Central Meteorological Observatory.†	202		

The observations at Hongo (Seismological Institute) and at Hitotsubashi, which form the principal object of our examination, were made by Professor Sekiya mostly by means of Ewing's horizontal pendulum and vertical motion seismographs, which magnify the horizontal motion 4 to 5 times and the vertical 7 to 8 times. On the other hand, the observations at the Central Meteorological Observatory were made by means of a Gray-Milne seismograph, which magnifies the horizontal and vertical movements 6 and 4 times respectively. In each case,

* Jour. Sc. Coll. Imp. Univ., Tokyo, Vol. II, p.p. 57-75.

† The Cental Meteorological Observatory is only 500 m to the south-west of Hitotsubashi.

the two horizontal components were in the east-west and north-south directions. Sometimes I have made also short references to the records given by ***duplex pendulum seismographs*** which write the horizontal motion, 6 or 7 times magnified, on a stationary glass plate.

The account of each earthquake is given more or less completely according to the following form.—

(1) Date and time of occurrence.

(2) Result of observation at the Central Meteorological Observatory. In cases of *strong* earthquakes, notes on the area of disturbance are also given.*

(The data in (1) and (2) are taken from the seismometrical reports of the Central Meteorological Observatory.)

(3) Detailed analysis of the seismograms obtained at Hitotsubashi and Hongo.

The times are always given in the ***First Standard Japan*** *Time*, or that of long. 135°*E.*

For finding the relation, if any, between the amplitude and period of vibration, I have constructed, in cases of some of the stronger earthquakes, tables giving these two elements of motion for the different vibrations, conveniently divided into groups in order of magnitude of the amplitude. In some cases, the examination was confined to a single component. If not specially mentioned, however, the measurement for the horizontal motion was made with referance to its two components, that is to say, the range of motion(2a) denotes the resultant horizontal displacement in each vibration.

* The extent of the disturbed area is given in sq. *ri*; 1 *ri* being very nearly equal to 4 km.

The *preliminary tremor, principal portion* and *end portion*, into which an earthquake motion may be divided, are defined as follows.— (1) The preliminary tremor is the introductory part, which consists of movements of small amplitude and of short period ; (2) the principal portion is the most active part which follows the preliminary tremor and consists of movements of large amplitude ; (3) the end portion denotes the feeble finishing part which follows the principal portion.

Ripples are those quick earthquake vibrations whose periods are small fractions of a second, generally superposed on slow principal undulations.

Intensity of motion. The intensity of ordinary, or non-destructive, earthquake motion is indicated as *slight, weak* or *strong*. A *slight* shock is one which is very feeble ; a *weak* shock is one whose motion is well pronounced but not so severe as to cause general alarm ; and finally a *strong* shock is one which is sufficiently sharp to throw down some furnitures, to cause people to run out of doors, etc.

A *tremor* denotes a very slight earthquake, whose amplitude is too small to be accurately measured.

Abbreviations.

The abbreviations used in the description of the seismograms are as follows.—

H.M.····Horizontal motion.

V.M.····Vertical motion.

2a ····Range of motion, or double amplitude.

T ····Period(complete)of vibration.

T_0 ····Period of vibration corresponding to max.2a.

$V=\frac{2\pi a}{T_0}$ =Maximum velocity.

$A = \frac{4\pi^2 a}{T_0^2}$ = Maximum acceleration.

2a is expressed in mm, and T_0 and T each in second.

Macro-seismic motion.

The motion of an earthquake when observed at no very great distance from the origin consists generally of a set of different waves whose periods range from fractions of a second up to 1 minute or more. Now the maximum motion (2a) in ordinary earthquakes as observed at Hitotsubashi is on average about 0.7 mm, while the lowest limiting value of the the acceleration (A) of the sensible earthquake motion is about 17 mm per sec. per sec.* If we, for example, put 2a = 0.7 mm. and $A = 17^{mm}/_{s^2}$, we obtain $T^2 = \frac{4\pi^2 a}{A}$; therefore $T = 0.9s$.

Similarly, if we put 2a = 5mm, and $A = 17\ ^{mm}/_{s^2}$, we obtain $T = 2.4s$.

The above calculations show that, with the ranges of motion of 0.7mm and 5 mm, the vibrations would not be sensible unless the period be smaller than 0.9s and 2.4s respectively. Now, as the motion is small in slight earthquakes, while the period is generally greater than 5 or 6 seconds in distant earthquakes;† so we may define the *macro-seismic motion* as a part of the earthquake motion whose period is, excepting cases of strong shocks, not longer than 2 or 3 seconds. Consequently the diagrams given by the ordinary Ewing or Gray-Milne seismographs, analyzed in the following pages, are to be regarded as indicating only the macro-seismic portions in the different earth-

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* See the *Publications*, No.11.

† In the diagrams of distant earthquakes there are often vibrations whose period is less than 1 sec., but the 2a of these movements is always very small.

quakes, the instruments not being able to record accurately the motion with period longer than $2\frac{1}{2}$ or 3 sec.

In No. 11 of the *Publications* I give a discussion of the analysis contained in the present volume, together with other miscellaneous notes.

Feb. 1902. Seismological Institute, Tokyo.

MACRO-SEISMIC MEASUREMENT IN TOKYO. I.

BY

F. OMORI, Dr. Sc.

Eqke No. 1. Sept. 26, 1885: 0.30.0 p.m.

Hitotsubashi ; horizontal motion.

The earthquake consisted of gentle vibrations. Max. 2a = 5.0 mm, T_0 = 1.8 s; V=8.7 mm/sec., A=30.5 mm/sec.² The relation between 2a and T of the horizontal motion is given in the following table.

HITOTSUBASHI ; HORIZONTAL MOTION.

2a (mm)		T (sec.)		2a (mm)		T (sec.)	
5.0	4.5 (mean)	1.8	2.0 (mean)	1.9	18. (mean)	1.5	1.17(mean)
5.0		2.0		"		0.92	
4.5		2.1		"		1.1	
4.3		2.6		"		"	
4.1		1.7		1.8		"	
4.0		1.8		"		1.2	
3.5	3.1 (mean)	1.5	1.6 (mean)	"		1.4	
3.3		1.7		1.6		1.1	
"		"		1.7		1.1	
"		"		1.5	1.4 (mean)	1.0	1.2 (mean)
"		1.4		"		0.95	
3.1		1.8		"		1.4	
2.9		"		"		"	
2.8		1.5		"		1.1	
"		1.8		1.3		1.5	
2.5	2.2 (mean)	2.1	1.3 (mean)	"		1.4	
2.3		1.1		1.2		0.84	
"		1.5					
2.1		1.2					
"		1.1					
2.0		1.2					
"		1.0					
"		1.2					

2a (mm)		T (sec.)		2a (mm)		T (sec.)	
1.1		0.84		0.7		0.44	
"		"		"		0.64	
"		0.89		"		0.74	
"		0.92		"		0.47	
1.0		0.77		0.6	0.57 (mean)	0.92	0.65 (mean)
"	0.96 (mean)	0.87	0.84 (mean)	"		0.61	
0.9		0.80		"		0.58	
"		0.54		0.5		0:80	
"		1.1		0.3		0.48	
0.8		0.69		"		0.77	
"		0.80					
"		1.0					

Eqke No. 2. July 2, 1886 : 0.33.6 p.m.

This was a moderately strong earthquake, the motion being chiefly in the EW component.

Hitotsubashi ; horizontal motion.

Max. 2a=1.5 mm, T_0=0.83 s ; V=5.7 mm/sec., A=43. mm/sec.^{2} The relation between 2a and T of the horizontal motion is given in the following table.

HITOTSUBASHI : HORIZONTAL MOTION.

2a (mm)		T (sec)		2a (mm)		T (sec.)	
1.5		0.83		0.75		0.83	
1.3	1.4 (mean)	0.86	0.85 (mean)	0.75		0.68	
1.5		0.86		0.75		0.75	
1.1		0.79		0.75		0.71	
1.0	1.0 (mean)	0.90	0.81 (mean)	0.75		0.79	
1.0		0.71		0.75		0.83	
1.0		0.83		0.75	0.74 (mean)	0.75	0.77 (mean)
0.9		0.83		0.75		0.75	
0.9		0.86		0.75		0.86	
0.9		0.86		0.75		0.86	
0.9	0.9 (mean)	0.83	0.83 (mean	0.75		0.68	
0.9		0.79		0.75		0.83	
0.9		0.90		0.75		0.71	
0.9		0.83		0.70		0.68	
0.8		0.75		0.70			

0.65		0.79					
0.65		0.79					
0.60		0.68					
0.60		0.56		0.30		0.79	
0.60		0.83		0.30		0.77	
0.55		0.75		0.30		0.75	
0.50		0.75		0.25		0.75	
0.50	0.26 (mean)	0.86	0.78 (mean	0.25	0.26 (mean)	0.79	0.78 (mean)
0.45		0.90		0.25		0.79	
0.40		0.83		0.25		0.79	
0.40		0.83		0.25		0.83	
0.38		0.83		0.20		0.79	
0.38		0.79					
0.38		0.75					
0.38		0.75					

From the above table, it will be seen that there was in this case no marked variation of the period. The following results have been obtained from the measurement of the vibrations in the very end part of the earthquake.

HITOTSUBASHI : HORIZONTAL MOTION, *CONT.*

2a (mm).	Number of Vibrations.	Average period (sec.)	
Very small	3	0.73	
,,	3	0.75	
,,	2	0.70	0.73 (mean)
,,	3	0.77	
,,	3	0.69	

Eqke No. 3. Dec. 26, 1886 : 5.48.5 p.m.

Hongo.

Horizontal motion. The motion consisted of small vibrations which were at first quick and irregular, but became, after a short interval, smooth and regular.

Vertical motion. The motion was maximum at the commencement,

gradually diminishing towards the end. The period remained very nearly constant as will be seen from the following table.

HONGO; VERTICAL MOTION.

	2a (mm)	Number of vibrations.	Average period (sec.)	
At the commencement of the eqke.	Very small.	5	0.43	0.42 (mean)
Towards the end.	"	7	0.39	
"	"	4	0.43	

Eqke No. 4. June 20, 1887 : 8.38.30 a.m.

Hitotsubashi.

The motion was rather greater in the *EW* than in the *NS* component, the period remaining constant.

HITOTSUBASHI : *EW* COMPONENT.

2a (mm)	Number of vibrations.	Average period (sec.)	
0.45	3	0.86	0.94 (mean)
0.38	3	0.90	
0.38	3	0.94	
0.38	2	1.0	
0.38	3	0.94	
0.38	3	0.94	
0.30	3	0.98	
0.25	3	0.94	
Very small	3	0.96	
"	3	0.96	

Hongo.

The motion was very small in all the three components, the period of vibration being as follows.

HONGO.

Component.	Number of vibrations.	Average period (sec.)	
EW.	4	0.59	0.69 (mean)
	4	0.73	
	4	0.74	
NS.	5	0.46	0.43 (mean
	4	0.46	
	3	0.44	
	4	0.46	
	3	0.42	
	5	0.41	
	5	0.41	
	5	0.40	
	5	0.44	
Vertical.	6	0.20	0.19 (mean)
	5	0.16	
	3	0.20	

Eqke No. 5. June 22, 1887 : 7.42.39 a.m.

This was a very small earthquake consisting of regular vibrations.

Hitotsubashi ; horizontal motion.

The motion was rather greater in the *EW* than in the *NS* component. The max. 2a was 0.14 mm in each component.

HITOTSUBASHI : HORIZONTAL MOTION.

Component.	Number of vibrations.	Average period. (sec.)		Component.	Number of vibrations.	Average period. (sec.)	
EW.	7	0.78	0.83 (mean)	*NS.*	4	0.72	0.78 (mean)
	3	0.71			4	0.70	
	6	0.80			3	0.92	
	6	0.88			10	0.76	
	6	0.86			6	0.78	
	6	0.75			6	0.76	
	4	0.88			10	0.69	
	5	0.78			10	0.84	
	3	0.96			10	0.86	
	5	0.81					
	7	0.90					

Hongo ; horizontal motion.

The motion was much greater in the *NS* than in the *EW* component there being no vertical motion.

HONGO ; *NS* COMPONENT.

2a (mm).	Number of vibrations.	Average period (sec.).	
0.12	4	0.44	0.43 (mean).
Very small	5	0.44	
——	4	0.47	
——	4	0.41	
——	5	0.42	
——	2	0.39	
——	4	0.42	

Eqke No. 6. June 30, 1887 : 8.0.35 a.m.

Hongo.

This was a very small earthquake.

Horizontal motion. The max. 2a was less than 0.1 mm ; the motion, which was almost entirely in the *NS* component, consisting of regular vibrations. The diagram indicated no preliminary tremour.

HONGO ; *NS* COMPONENT.

2a (mm).	Number of vibrations.	Average period (sec.).	
Small.	3	0.45	0.44 (mean).
,,	3	0.45	
Very small.	5	0.46	
,,	5	0.44	
,,	2	0.43	
,,	2	0.41	
,,	5	0.44	
,,	5	0.42	
,,	5	0.42	
,,	2	0.43	

Vertical motion. The duration of the vertical motion was somewhat shorter than that of the horizontal. The period remained perfectly constant, the average value, deduced from 39 vibrations, being 0.18 s. The max. 2a was very small.

Eqke No. 7. July 2,1887 : 3.16.24 p.m.

Hongo.

Horizontal motion. The motion occurred equally in the two horizontal directions and consisted of small regular vibrations, whose period remained perfectly constant in each component. The average period was as follows :--

EW......0.72 s (deduced from 30 vibrations);
NS......0.44 s („ „ 41 „).

The origin of the earthquake was situated due *W* from Tokyo, so that the *EW* component may be taken as representing the *normal vibration*.

Vertical motion. The motion, which was maximum at the commencement and thence gradually diminished, consisted of small regular movements whose average period, deduced from 18 vibrations, was 0.17s.

Eqke No. 8. July 12, 1887 : 3.7.42 p.m.

This was a very small earthquake.

Hitotsubashi.

Horizontal motion. The motion consisted of regular vibrations, the max. 2a being 0.14 mm in the *EW* and 0.1 mm in the *NS* component. The average period was as follows :—

EW......0.71 s (deduced from 28 vibrations);
NS......0.74 s („ „ 9 „).

Hongo.

The motion which consisted of vibrations of a constant period, was almost entirely in the *NS* component. The max. 2a was 0.14 mm, and the average period, deduced from 28 vibrations in the *NS* component, was 0.46s. There was no vertical motion.

Eqke No. 9. July 22, 1887 : 8.27.0 p.m.

This was an earthquake of moderate intensity.

Hongo.

Horizontal motion. The *NS* component consisted of regular movements of constant period, whose max. 2a was 0.25 mm and whose average period, deduced from 53 vibrations, was 0.46s. On the other hand, the *EW* component consisted of slow gentle movements of variable period, whose max. 2a was 0.4 mm and whose average period deduced from 15 vibrations, was about 1.0 sec.

Vertical motion. The vibrations occurred only in the earlier part of the earthquake. The 2a was very small, the average period, deduced from 22 vibrations, being 0.14 s.

Eqke No. 10. Sept. 2, 1887 ; 5.52.49 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 10s.

Direction. *E-W.*

Max. H. M. 0.4 mm (period = 0.7s).

Max. V. M. Small.

Character. Quick.

Hitotsubashi.

Horizontal Motion. Duration = 50s.

Max. 2a = 0.21 mm, $T_0 = 0.54$ s ; $V = 1.2$ mm/s, $A = 14.2$ mm/s.² The average period was as follows :—

EW .... 0.52 s (deduced from 24 vibrations) ;

NS .... 0.55 s („ „ 16 „).

Hongo.

Horizontal motion. The motion consisted at first of very quick vibrations. After a short time interval these *ripples* disappeared, and there followed regular and somewhat larger movements, whose period remained constant till the end of the earthquake, and whose average period, deduced from 68 vibrations in the *NS* component, was 0.44s. The motion was chiefly in the *NS* component.

Max.$2a = 0.2$ mm; $T_0 = 0.45$ s; $V = 1.4$ mm/s, $A = 19.5$ mm/s².

Vertical motion. The vertical motion consisted of a series of extremely small regular vibrations, whose maximum occurred at the commencement. The period was constant, the average value, deduced from 40 vibrations, being 0.16 s. It may be noted that the character of the vertical motion was much different from that of the horizontal, the maximum in the latter component occurring some seconds after the start when the movements became free of the superposed ripples. It seems probable, however, that the vertical vibrations and the horizontal *ripples* belong to one and the same class of waves.

Eqke No. 11. Sept. 3, 1887; 4.50.30 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 13. Sept. 5, 1887; 3.23.23 p.m.

Observation at the *Cent. Met. Observatory*:—

Duration. 6 m.

Direction. *SE—NW.*

Max. H.M. 25.7 mm(period = 2.3s).

Max. V.M. 6.5 mm(period = 0.8s)

Character. Quick

Remark. "The earthquake began with tremors which lasted 7s. Then the horizontal motion became active and indicated 34 large vibrations; the maximum having occurred at the 32nd second. At the 46th second the motion became small, but after a short interval it increased again, being more or less active for the first 1m 50s. The maximum of the vertical motion, whose character was sharp from the commencement, occurred at the 18th second, or 14s earlier than the maximum horizontal motion. The vertical motion was more or less active till the 56th second. This earthquake was the strongest in this year next to that of the 15th of January.

"The total land area of disturbance was 4660 sq. *ri* and extended over the following 16 provinces:— Suruga, Kai, Izu, Sagami, Musashi,

Awa, Kazusa, Shimosa, Hitachi, Kotsuke, Shimotsuke, Shinano, Iwaki, Iwashiro, Echigo and Rikuzen. The motion was felt *strongly* in the eastern part of Sagami, eastern part of Musashi, Awa, Kazusa, Shimosa, Hitachi, eastern part of Kotsuke, eastern part of Shimotsuke, and in the southern portion of Iwaki. The area of *violent* motion was about 150 sq. *ri* and extended over the eastern portion of Kazusa, eastern portion of Shimosa and the south-eastern portion of Hitachi.

"The reports from some of the places in the *violently* or *strongly* shaken area were as follows.—

"*Shimosa.* In the Katori District, vertical motion was felt first, soon followed by horizontal shakings, which caused some damage such as cracking of house walls, falling down of roof tiles, overturning of furnitures, overflowing of liquids, etc. An old ware house was overthrown, while several dwelling houses were thrown out of the vertical position. Some *shōu* brewers sustained losses from the fracturing of the chimneys and the overturning of the large vessels which contained several thousand *koku* of *shōu*. Porcelain dealers had also much of their articles broken. In Kaijō District, house walls were cracked, liquids overflowed and people generally ran out of doors. In Sosa District, some ware houses were damaged, the motion having been so violent that a man working on the roof of a house was thrown down.

"*Kazusa.* In the Nagara District, the earthquake began with vertical tremors, followed after a short interval by horizontal shakings, which became so strong that people ran out of houses. Some *dozo* (Japanese ware houses) were cracked, waters contained in tubs overflowed towards east or north and loosely piled fagots fell down towards *NE.* Porcelain dealers sustained losses from the overturning of their articles.

"*Hitachi.* In the Kajima District the shaking was felt simultaneously with sounds. The water which filled a tub to about 4 inches from the mouth partly overflowed toward *S.* In some of the other districts pendulum clocks were stopped and furnitures were overthrown.

"In *Kazusa*, Shimosa and the eastern part of Hitachi, this earthquake was the strongest next to that in the winter of 1884."

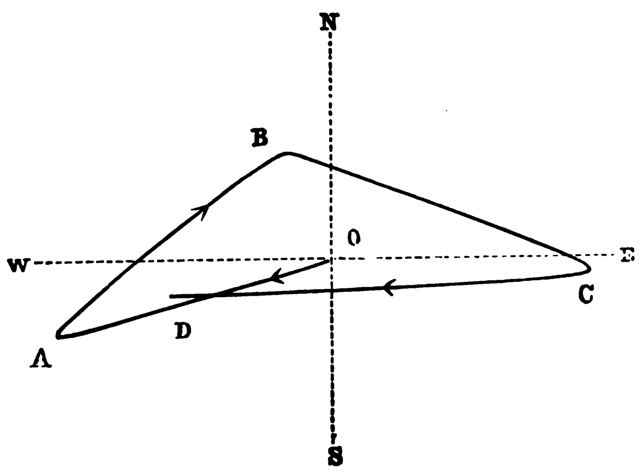
Hongo.

The horizontal motion of this earthquake was much greater, but of slower period, than that of the earthquake of Jan. 15th, 1887. The vertical motion was small.

Horizontal motion. The duration was as follows:—

EW component............$4\frac{1}{2}$ m;
NS " ....$3\frac{1}{2}$ m.

The motion was much greater in the *EW* than in the *NS* component, probably because the origin was to the east of Tokyo. At first there were some superposed *ripples*, which, however, were insignificant.



Scale: $^{4.7}/_{1}$

The preliminary tremor lasted 15s, when took place the following maximum vibration (*OABCD* in the accompanying figure):—

Max. $2a = 15$mm, *Direction* $N\,84°E$, $T_0 = 3.0$s; $V = 15.7$ $^{mm}/_{s}$, $A = 33^{mm}/_{s^2}$

During the first 40s, the motion was complicated, but thereafter it became gradually regular. The vibrations in the *NS* component were quicker and more regular than those in the *EW* component. The relation between 2a and *T* of the vibrations in the *NS* component after 40s from the commencement is given in the following table.

HONGO : *NS* COMPONENT.

2a(mm)		Number of vibrations	T (sec.)		2a(mm)		Number of vibrations	T (sec.)	
1.7		1	0.9						
1.3		1	0.81						
1.0		1	0.72						
1.0	1.1 (mean)	1	0.9	0.75 (mean)	0.3		2	0.54	
0.9		1	0.68		0.3		2	0.45	
0.8		1	0.63		0.3		1	0.41	
0.8		1	0.63		0.3		8	0.54	
0.7		1	0.68		0.2		3	0.43	
0.6		1	0.50		0.2		3	0.42	
0.6		1	0.59		0.2		6	0.47	
0.6		1	0.45		0.2	0.20 (mean)	3	0.45	0.47 (mean)
0.6		5	0.65		0.2		6	0.48	
0.6		1	0.72		0.2		6	0.47	
0.56	0.50 (mean)	1	0.77		0.2		4	0.50	
0.5		1	0.51	0.57 (mean)	0.2		4	0.50	
0.4		1	0.45		0.1		6	0.51	
0.4		2	0.50		0.1		5	0.50	
0.4		4	0.50		0.1		3	0.45	
0.4		1	0.60						
0.4		1	0.72						
0.36		1	0.45						

In the *NS* component, the period became very nearly constant towards the end.

In the *EW* component, the average period, deduced from 11 vibrations in the end portion, was 1.3s.

Vertical motion. Duration=80s. The motion, which was more or less active during the first 40s, was at first irregular but became regular towards the end. There were two equal maxima which occurred respectively at the 15th and 18th seconds:

Max. 2a = 0.48mm, T_o=0.61s ; V=2.5 mm/s, A=25mm/s.²

It will be observed that the first vertical maximum occurred simultaneously with the maximum in the horizontal component.

The relation between 2a and T of the vertical motion is given in the following table.

HONGO : VERTICAL MOTION.

2a (mm)		Number of vibrations.	Average T (sec.)		2a (mm)	Number of vibrations.	Average T (sec.)	
0.50	0.42 (mean)	1	0.51	0.54 (mean)	Very small	4	0.15	0.16 (mean)
0.44		1	0.66		,,	4	0.13	
0.31		1	0.44		,,	3	0.17	
0.25	0.23 (mean)	1	0.40	0.39 (mean)	,,	7	0.18	
0.25		1	0.44		,,	4	0.15	
0.21		1	0.36		,,	2	0.18	
0.19		1	0.36		,,	6	0.17	
0.15	0.13 (mean)	1	0.27	0.28 (mean)	,,	3	0.18	
0.15		1	0.29		,,	5	0.22	
0.13		1	0.24		,,	2	0.15	
0.13		3	0.27		,,	3	0 15	
0.13		1	0.33		,,	3	0.14	
0.06		2	0.28		,,	4	0.15	

Eqke No. 13. Sept. 4 1887 :—

Not observed at the *Cent. Met. Observatory.*

Hitotsubashi.

Horizontal motion. This was a very small earthquake which consisted of gentle shakings, the motion being chiefly in the *EW* direction.

Max. $2a=0.3\text{mm}$, $T_c=0.8\text{s}$; $V=1.2^{\text{mm}}/_{\text{s}}$, $A=9.3^{\text{mm}}/_{\text{s}^2}$. The average period, deduced from 44 vibrations in the *NS* component, was 0.72s.

Vertical motion. Very slight.

Eqke No. 14. Sept. 6, 1887 :—

Not observed at the *Cent. Met. Observatory.*

Hitotsubashi.

Duration = 120s. The motion, which was slightly greater in the *EW* than in the *NS* direction, consisted of a series of very regular gentle vibrations, there being no vertical component. The following maximum motion occurred at the 4th second :—

Max. $2a=0.64$ mm, $T_0=1.1$s; $V=1.8^{mm/s}$, $A=10.4^{mm/s^2}$.

The average period, deduced from 24 vibrations in the *EW* component, was 0.83s. The motion in the *NS* component was irregular.

Hongo.

The motion, which consisted of smooth regular vibrations, was much greater in the *EW* than in the *NS* component.

Eqke No. 15. Sept. 8, 1887; 3.55.0 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 16. Sept. 11,1877; 9.20.0 a.m.

Observation at the *Cent. Met. Observatory*:—

Duration.	25s.
Direction.	*E–W.*
Max. H.M.	Small.
Character.	Gentle.

Eqke No. 17. Sept. 13, 1887; 8.16.52 p.m.

Observation at the *Cent. Met. Observaiory*:—

Duration.	12s.
Direction.	*SW–NE.*
Max. H.M.	0.2mm (period=1.2s).
Character.	Gentle.

Hongo.

Duration=65s. The motion, which occurred equally in the two horizontal components, consisted of gentle vibrations, there being no vertical component.

Max. $2a=0.05$mm, $T_0=0.6$s; $V=0.3\,^{mm}/_{s}$, $A=2.7\,^{mm}/_{s^2}$. The motion, which was at first irregular, became afterwards regular, the average period being as follows:—

(*EW*)	1.4s	(deduced from 12 vibrations);
(*NS*)	0.50s	(„ „ 26 „).

Eqke No. 18. Sept. 15, 1887; 4.41.41 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 3s.

Direction. *E-W.*

Max.H.M. 0.2mm (period = 0.3s).

Character. Quick.

Eqke No. 19. Sept. 25, 1887 ; 8.56.11 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 2m.

Direction. *ESE—WNW.*

Max. H. M. 1mm (period = 1.8s).

Max. V. M. Small.

Character. Gentle.

Hitotsubashi

Duration = 3m. The motion was much larger in the *EW* than in the *NS* component.

Max.2a = 1.7mm, Direction $S\ 70^\circ W$, $T_0 = 0.84$s ; $V = 6.4\ ^{mm}/_{s}$, $A = 47.6\ ^{mm}/_{s^2}$. The average period, deduced from 13 vibrations in the *EW* component, was 0.77s.

The *Duplex Pendulum* at Hitotsubashi indicated two principal directions of motion, namely, *ENE—WSW* and *ESE—WNW*, the amplitude being greater in the former direction.

Hongo.

The duration was as follows :—

(*EW*)................116s ;

(*NS*)..................87s.

The preliminary tremor lasted 1.2s, when the following maximum motion took place :—

Max. 2a = 0.5mm, $T_0 = 0.5$s ; $V = 3.1\ ^{mm}/_{s}$, $A = 39.5\ ^{mm}/_{s^2}$.

In the *end portion* of the *NS* component, when the superposed ripples disappeared, the average period was 0.48s. The motion in the corresponding portion of the *EW* component consisted of slow undula-

tions of an average period of 0.93s, superposed with smaller ones of an average period of about 0.53s. These latter vibrations existed also in the earlier part of the earthquake and had an average period of 0.42s. Vertical motion did not exist.

The *Duplex Pendulum* at Hongo indicated the same two principal directions of motion as at Hitotsubashi.

Eqke. No. 20. Nov. 15, 1887 ; 3.54.51 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 2m.

Direction. *SE-NW.*

Max. H.M. 0.4mm (period = 2.4s).

Character. Gentle.

Hongo.

Horizontal motion.

Duration = 70s. The motion was greater in the *EW* than in the *NS* direction, the vertical component being very small.

Max. 2a = 0.16mm, T_0 = 0.6s ; V = 0.8 mm/s, A = 8.8 mm/s².

Vertical motion.

Max. 2a = 0.06mm. T_0 = 0.5s ; V = 0.4 mm/s, A = 4.7 mm/s².

Eqke No. 21. Nov. 20, 1887 ; 0.2.81 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 45s.

Direction. *SWS-NEN.*

Max. H.M. 0.2mm (period = 0.5s).

Character. Quick.

Hitotsubashi.

Horizontal motion. Duration = 3m. The motion was greater in the *NS* than in the *EW* component.

The average period deduced from 16 vibrations in the *NS* component, was 0.63s.

Vertical motion. Duration = 40s.

Max. $2a = 0.3$mm, $T_o = 0.5$s ; $V = 1.9$ mm/s, $A = 23.7$ mm/s².

The average period, deduced from 22 vibrations, was 0.45s.

Hongo.

Horizontal motion. Duration = 57s.

The diagram indicated no preliminary tremor, but began at once with the max. $2a$ of 0.24mm in the NS and 0.08mm in the EW direction. The motion, which was much greater in the NS than in the EW component, consisted, in the former, during the first 8.1s of quick and irregular vibrations of an average period of 0.18s ; thereafter the vibrations became regular and slow, the average period, deduced from 60 vibrations, being 0.47s. In the EW component it was difficult to count the number of vibrations.

Vertical motion. Duration = 12.5s.

The vertical motion existed in a comparatively large amount and consisted of a series of regular vibrations of an average period of 0.18s. The max. $2a$ of 0.16mm occurred soon after the commencement.

Eqke No. 22. Nov. 23, 1887 ; 6.5.0 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 23. Nov. 30, 1887 ; 9.24.18 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	90s.
Direction.	*SES-NWN.*
Max. H.M.	1.3mm (period = 1.2s).
Character.	Gentle.

Remark. The motion was at first small. The maximum vibration occurred at the 15th second.

Hitotsubashi.

Horizontal motion. Duration = 100s. The motion, which was chiefly in the EW direction, consisted of gentle vibrations.

Max. $2a = 0.64$mm, *Direction SE,* $T_o = 0.96$s ; $V = 2.1$ mm/s, $A = 13.6$ mm/s².

The average period was 0.83s.

Hongo.

***Horizontal motion.* Duration = 90s.**

The preliminary tremor lasted 2.0s. The motion which was greater **in the *NS* than in the *EW* component, was during the first** 10s super-**posed with small ripples of an average period of 0.16s;** thereafter the **vibrations became simple and regular.**

Max. 2a = 0.6mm, *Direction* *S*, T_0 = 1.3s; *V* = 1.5 mm/s,
A = 7.0 mm/s.²

The average period in the *NS* component was as follows :—

during the	**1st 9.8s......**	**Aver. period**	**= 0.45s;**
„ „	**next 18.0s......**	**„ „**	**= 0.45s(max. 2a** = 0.3mm);
„ „ „	**17.5s......**	**„ „**	**= 0.44s(„ „** = 0.18 „);
„ „ „	**5.7s......**	**„ „**	**= 0.45s(motion** very small).

In the *EW* component, the vibrations were irregular but had an **average period of about 0.6s; towards the very end they** became small **and slow and had an average period of 0.77s.**

***Vertical motion.* Duration = 45s.**

The vertical motion, whose amount was comparatively large, consisted of a series of regular vibrations, whose max. 2a was 0.06mm, and whose average period was as follows :—

50 vibrations	during the 1st 8.5s	gave an aver. period of 0.21s;
50 „	„ „ next 8.5s	„ „ „ „ „ 0.21s,
50 „	„ „ „ 8.5s	„ „ „ „ „ 0.21s.

The motion was small at the commencement, but the preliminary tremor was not well defined.

Eqke No. 24. Dec. 5,1887 ; 0,57.16 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 15s.

Max. H. M. Very small.

The *Duplex Pendulum* at *Hongo* indicated very small movements, chiefly in the *SES—NWN* direction.

Eqke No. 25. Dec. 8,1887 : 8.3.0 p.m.

Not observed at the *Cent. Met. Observatory* :—

Hitotsubashi.

Duration = 60s. The motion was chiefly in the *EW* direction.

Max. 2a = 0.2mm, $T_o = 0.8$s ; $V = 0.8$ mm/s, $A = 6.2$ mm/s.²

The average period was 0.8s.

Hongo.

Duration = 70s. The motion, which consisted of regular gentle vibrations, was greater in the *NS* than in the *EW* direction ; there being no vertical component.

Max. 2a = 0.2mm, $T_o = 0.5$s ; $V = 1.3$ mm/s, $A = 15.8$mm/s.²

The average period, deduced from 88 vibrations in the *NS* component, was 0.46s.

Eqke No. 26. Dec. 11,1887 ; 9.55. 47 p.m.

Observed as a tremor at the *Cent. Met. Observatory.*

The *Duplex Pendulum* at *Hitotsubashi* recorded motion chiefly in the *SE—NW* direction.

Eqke No. 27. Dec. 14, 1887 ; 10.55.9 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 150s.

Direction. *SES—NWN.*

Max. H.M. 0.3mm(period = 2s).

Character. Gentle.

The *Duplex Pendulum* at *Hitotsubashi* recorded motion chiefly in the *ENE—WSW* direction.

Eqke No. 28. Dec. 16,1887 ; 8.28.21 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 120s.

Direction. *ESE—WNW.*

Max. H.M. 2.5mm(period = 1.5s).

Max. V.M. 0.3mm(period = 0.4s).

Character. Quick.

Remark. The preliminary tremor lasted for 7s, when the horizontal motion became suddenly active, the vertical motion appearing at the same moment. After 10s the intensity began gradually to diminish.

Hongo.

Horizontal motion. Duration=100s. The preliminary tremor lasted for 3s, when the following maximum motion suddenly took place :—

Max. $2a=2.4\mathrm{mm}$, *Direction* $N\,15°\,W$, $T_0=0.8\mathrm{s}$; $V=9.4\,\mathrm{mm/s}$, $A=74\,\mathrm{mm/s^2}$.

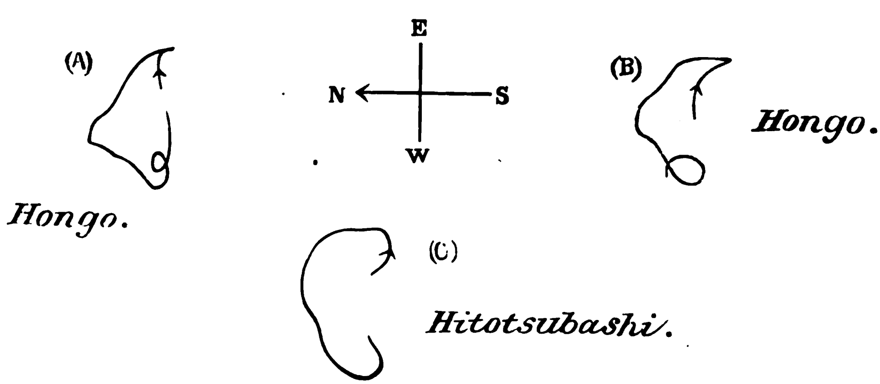
There was no corresponding prominent vibration in the vertical component. The movements, which followed the maximum, were much smaller ; their average period, deduced from 114 vibrations in the NS component, being 0.53s. The ripples existed till about 23rd second.

Vertical motion. Duration=50s. For the first 18s, the motion consisted of nearly uniform quick vibrations, there being no prominent large displacement.

Max. $2a=0.11\mathrm{mm}$, $T_0=0.25\mathrm{s}$; $V=1.4\,\mathrm{mm/s^2}$, $A=34.8\,\mathrm{mm/s^2}$

After the 18th second the motion became abruptly very small.

The two *Duplex Pendulums* at Hongo gave almost identical diagrams (A and B in the accompanying figure), which show that the very first active motion was towards E, followed by two nearly equal displacements($=2.4$mm)directed respectively toward NW and SE. The rest of the shaking was small.



The *Duplex Pendulum* at *Hitotsubashi* gave a diagram (*C* in the accompanying figure) very similar to those at *Hongo*; the maximum motion(=2.8mm) was directed toward *SW.*

Eqke No. 29. Dec. 17, 1887 ; 0.17.8 a.m.

Observation at the *Cent. Met. Observatory*:—

Duration. 10s.

Max. H.M. Small.

Character. Quick.

Hitotsubashi.

The *Duplex pendulum* gave a very simple diagram, the motion being in two mutually rectangular directions, namely, *E—W* and *N—S.* Max. 2a=0.3mm.

Hongo.

Duration=40s. The motion consisted of small gentle horizontal shakings, the vertical motion being very slight.

Max. 2a=0.2mm, $T_0=0.7s$; $V=0.9$ mm/s, $A=8.1$ mm/s.²

Eqke No. 30. Dec. 17,1887 ; 6.18.22 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 31. Dec. 17, 1887 ; 11.41.14 p.m.

Observation at the *Cent. Met. Observatory*:—

Duration. 10s.

Direction. *E—W.*

Max. H. M. 0.25s (period=0.6s)

Character. Gentle.

Hitotsubashi.

Duration=85s.

Max. 2a=0.2mm, $T_0=0.8s$; $V=0.8$ mm/s, $A=6.2$ mm/s.²

The average period was 0.71s.

The *Duplex pendulum Hitotsubashi* at indicated movements chiefly in the *ESE—WNW* direction.

Hongo.

Horizontal motion. Duration = 45s.

Max. 2a = 0.2mm, T_0 = 0.4s ; V = 1.6 mm/s, A = 24.6 mm/s.²

The average period was 0.59s.

Vertical motion. Duration = 10s. The motion was very small, the average period being 0.03s.

Eqke No. 32. Dec. 19, 1887 ; 6.0.12 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 33. Dec. 21, 1887 ; 2.5.55 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 15s.

Max. H. M. Very small.

Eqke No. 34. Dec. 24, 1887 ; 4.9.41 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 35. Dec. 24, 1887 ; 7.51.38 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 60s.

Direction. *SW—NE.*

Max. H.M. 0.2mm(period = 2s).

Character. Gentle.

Hitotsubashi.

Duration = 120s.

Max. 2a = 0.2mm, T_0 = 0.8s ; V = 0.8 mm/s, A = 6.2 mm/s.²

The average period was 0.78

Eqke No. 36. Dec. 27, 1887 ;——

A very small earthquake, not observed at the *Cent. Met. Observatory.*

Hitotsubashi.

Horizontal motion. Duration = 83s. The motion was slightly larger in the EW than in the NS component.

Max. 2a = 0.1mm, $T_0 = 0.7$s ; $V = 0.5$ mm/s, $A = 4$ mm/s.²

There was no vertical motion.

According to the *Duplex Penduluni* diagram at Hitotsubashi, there were two principal directions of motion, namely, E-W and N-S, the motion in the former direction being greater than that in the latter. This may indicate that the earthquake origin was towards E or W of Tokyo and gave rise to the normal and transverse sets of waves.

Eqke No. 37. Dec. 31, 1887 ; 1.24.45 a.m.

A small shock observed only at the *Cent. Met. Observatory.*

Eqke No. 38. Jan. 1, 1888 ; 3.31.38 p.m.

Hitotsubashi.

Duration = 100s. The motion, which consisted of perfectly regular vibrations, was much greater in the NS than in the EW component, there being no vertical motion. The earthquake began very gently, soon reached the maximum, and then gradually decreased.

Max. 2a = 0.28 mm in the EW and 0.2 mm in the NS component ; $T = 0.9$s ; $V = 1.0$ mm/s, $A = 6.8$ mm/s.²

The average period of vibration (NS component) was as follows :—

25 vibrations during the first 22.5s gave an aver. period of 0.90s ;

24 „ „ „ next 20.4s „ „ „ „ „ 0.85s ;

46 „ „ „ 38.2s in the very end part of the earthquake gave an aver. period of 0.83s.

Thus the period remained very neary constant, becoming, however, slighty shorter towards the end.

Eqke No. 39. Jan. 11, 1888 ; 8.50.36 a.m.

This was an earthquake of moderate intensity.

Observation at the *Cent. Met. Observatory.*

Duration = 60s.

Direction. *ESE-WNW.*

Max. H.M. 0.4mm (period=1.8s).

Max. V.M. ———

Character. Gentle.

Hitotsubashi.

Duration=120s. The motion was much greater in the *NS* than in the *EW* direction, there being no vertical component. The following maximum motion occurred at about 2s after the commencement :—

Max. 2a=0.6mm, T_0=0.79s ; V=2.4 mm/s, A=19 mm/s.²

Each horizontal component motion consisted of a series of very regular simple harmonic vibrations. In the *NS* component, the amplitude was great at the commencement, then became small, and then again increased, etc., thus presenting a series of maximum and minimum groups. The maximum displacements occurred at 2s, 7s, 26s and 43s respectively after the commencement. The relation between the 2a and *T* of vibration in the *NS* component is given in the following table.

HITOTSUBASHI : *NS* COMPONENT.

2a (mm)		T (sec.)		2a (mm		T (sec.)	
0.5		0.91		0.3		0.74	
0.5		0.89		0.3		0.78	
0.45	0.45 (mean)	0.87	0.89 (mean)	0.3		0.76	
0.45		0.87		0.3		0.79	
0.43		0.91		0.28		0.69	
0.40		0.87		0.28		0.87	
0.40		0.87		0.25	0.27 (mean)	0.74	0.78 (mean)
0.38		0.87		0.25		0.71	
0.38		0.87		0.25		0.74	
0.38		0.84		0.25		0.81	
0.38		0.80		0.25		0.87	
0.38	0.38 (mean)	0.80	0.88 (mean)	0.25		0.82	
0.38		0.93		0.25		0.82	
0.38		0.88		0.2		0.74	
0.38		0.78		0.2		0.80	
0.38		0.82		0.2		0.78	
0.35		0.95		0.2	0.19 (mean)	0.78	0.77 (mean)
0.35		0.99		0.2		0.81	
0.35		0.99		0.15		0.72	

The measurement in the above table was taken from the earlier portion of the earthquake. Towards the very end, the mean period was 0.78s.

The above table indicates a slight variation of the period with amplitude. The period, however, remained on the whole constant. Thus, arranging the 37 vibrations given in the table in order of time, the first 19 give an average period of 0.82s, while the remaining 18 give an average period of 0.84s.

Hongo.

Horizontal motion. Duration = 65s. As at Hitotsubashi, the motion was much greater in the *NS* than in the *EW* component.

Max. 2a = 0.32mm, $T_0 = 0.48$s ; $V = 2.1$ mm/s, $A = 28$ mm/s.²

In the *NS* component, which was greatest at the commencement and indicated a series of alternations of maximum and minimum groups, the motion consisted of regular simple vibrations, whose average period, deduced from 51 vibrations, was 0.43s. In the *EW* component, the motion, which was at first irregular, became afterwards regular and had an average period of 0.77s.

The ripples which existed in the earlier part of the *EW* component, had an average period of 0.17s.

Vertical motion. Duration = 22s.

The motion, which was most active at the commencement and thence gradually decreased, consisted of very small regular vibrations, whose average period, deduced from 27 vibrations, was 0.17s.

Max. 2a = 0.06mm, $T_0 = 0.19$s ; $V = 1$ mm/s, $A = 33$ mm/s.²

It will be observed that, in this case, the period of vibration of the vertical motion was equal to that of the ripples in the *EW* component.

Eqke No. 40. Jan. 13, 1888 ;——

Hitotsubashi.

This was a very small earthquake, chiefly in the *EW* component.

The average period, deduced from 45 vibrations in the *EW* component, was 0.64s.

Eqke No. 41. Jan. 14, 1888 ; 5.31.55 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 15s.

Direction. *E–W*.

Max. H.M. Small.

Max. V.M. Very small.

Character. Quick.

Eqke No. 42. Jan. 27, 1888 ; 10.5.33 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 10s.

Direction. *N–S*.

Max. H.M. Small.

Character. Gentle.

Hitotsubashi.

Duration = 60s. The motion was almost exclusively in the *EW* direction, there being no vertical component. The diagram consists of regular simple harmonic curves.

Max. $2a = 0.38$mm, $T_0 = 0.91$s ; $V = 1.3$ mm/s, $A = 9.1$ mm/s.

The average period, deduced from 11 vibrations in the *EW* component, was 0.89s.

The Duplex Pendulum at Hitotsubashi recorded movements almost entirely in the *EW* direction.

Eqke No. 43. Feb. 2, 1888 ; 1.15.15 p.m.

This was the first and strongest of the four earthquakes which occurred on the afternoon of the 2nd of February.

Observation at the *Cent. Met. Observatory* :—

Duration. 228s.

Direction. *ESE—WNW*.

Max. H.M. 13mm (period = 3.7s ?)

Max. V.M. 0.5mm.

Character. Quick.

Remark. The earthquake began with tremors in the *EW* direc-

tion, the tremors in the *NS* component occurring 11s later on. At 23rd second, large movements began to appear in the *EW* component, accompanied by active vertical movements, while in the *NS* component the motion became large first at the 33rd second. The maximum vibration occurred at the 42nd second, the motion remaining still active for the next 63s.

Area of disturbance. The earthquake, whose total land area of disturbance covered 3420 sq. *ri*, was felt in the following 16 provinces: Hitachi, Shimosa, Kazusa, Awa, Musashi, Sagami, Kai (eastern part), Suruga (north-eastern portion), Shinano (eastern portion), Kozuke, Shimotsuke, Echigo(eastern portion), Iwashiro, Iwaki, Uzen (south-eastern portion) and Rikuzen (southern part).

The area of *strong* motion was 450 sq. *ri* and included the provinces of Hitachi (southern part), Shimosa, Kazusa (northern portion) and Musashi (eastern portion). The motion was felt very strongly in the Kajima District of Hitachi, where the direction was *SE–NW* or *S–N*, and where liquids were thrown out. In Kaijō District of Shimosa the earthquake was less severe than that of Sept. 5, 1887. In Tokyo, some pendulum clocks were stopped. The 2nd earthquake, observed in Tokyo at 2.23.46 p.m., was less strong and was felt in the eight provinces of Hitachi, Kazusa, Shimosa, Musashi, Kozuke, Shimotsuke, Iwaki and Iwashiro. The 3rd earthquake, observed in Tokyo at 3.0.14 p.m., was in some places felt *weakly;* the area of disturbance including the five provinces of Hitachi, Kazusa, Shimosa, Musashi and Shimotsuke. The 4th earthquake, observed in Tokyo at 3.41.27 p.m., was felt *strongly* in the southern part of Hitachi and the eastern part of Shimosa; the area of disturbance including the following 12 provinces: Hitachi, Kazusa, Awa, Musashi, Shimosa, Sagami, Shimotsuke, Kozuke, Iwaki, Iwashiro, Uzen and Rikuzen.

Hongo.

Horizontal motion.

Duration = 130s (*EW* component);

" = 110s (*NS* ").

The preliminary tremor lasted 3.6s in the *EW* and 7.2s in the *NS* component.

The motion, which was larger in the *EW* than in the *NS* component, consisted in the latter of moderate vibrations, which were at first irregular but afterwards became regular and neary constant in amplitude, there being no very prominent wave. In the *EW* component, there were some large movements, the motion being more complicated than in the other component.

The maxima did not occur simultaneously in the two components, the *EW* maximum happening earlier than the *NS* one. The times of occurrence of these displacements were as follows :—

EW COMPONENT.

1st	Max.	occurred	3.6s	after	the	commencement,	....(1)
2nd	,,	,,	10.s	,,	,,	,,	,....(2)
3rd	,,	,,	17.s	,,	,,	,,	,....(3)
4th	,,	,,	25.s	,,	,,	,,	,....(4)

NS COMPONENT.

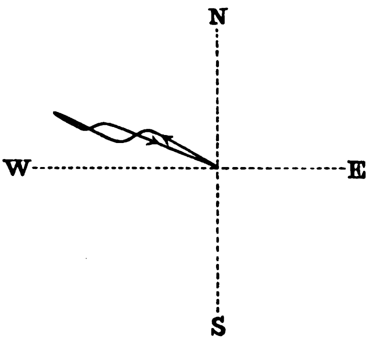
1st	Max.	occurred	7.2s	after	the	commencement,	....(1′)
2nd	,,	,,	17.s	,,	,,	,,	,....(2′)
3rd	,,	,,	24.s	,,	,,	,,	,....(3′)
4th	,,	,,	31.s	,,	,,	,,	,....(4′)

If the displacements (1) to (4) in the *EW* component be regarded as corresponding respectively to the displacements (1′)....(4′) in the *NS*, we may conclude that the waves of the former component reached in the mean about 6s earlier than those of the latter. Now, as the origin of the earthquake was situated due east of Tokyo, the *EW* component would correspond to the normal wave and the *NS* component to the transverse wave.

The absolutely maximum motion, which occurred about 17s after the commencement was the following :—

Max. 2a = 2.0mm, *Direction* $W\,20°\,N$, $T_0 = 1.3\text{s}$; $V = 4.8\,\text{mm}/\text{s}$, $A = 23\,\text{mm}/\text{s}^2$.

Then there followed a counter displacement of nearly equal amplitude towards the opposite direction. (See the annexed diagram.)



The periods of vibration in the two components are given next.—

In the EW component the average period of the ripples, which existed in the earlier part, was 0.16s; in the NS component the corresponding period was 0.13s. In the former component, the ripples lasted about 20s. The average period of vibrations in the end portion was 0.86s in the EW and 0.47s in the NS component.

Vertical motion. Duration = 34s.

The motion was nearly uniform, there being no preliminary tremor. The max. 2a was the following:—

Max. 2a = 0.18mm, $T_0 = 0.43$s; $V = 1.3^{\mathrm{mm}}/_{\mathrm{s}}$, $A = 19^{\mathrm{mm}}/_{\mathrm{s}^2}$

This occurred 11s after the commencement, there being a second maximum 5s later on. These movements did not occur simultaneously with the maxima in the EW direction the period being also widely different in these two components, which seemed to be totally independent of each other. This fact shows that the vertical motion was not, in this case, the vertical component of the normal wave.

The average period deduced from 30 vibrations was 0.29s.

The Duplex Pendulum at Hongo indicated motion chiefly in the directions ESE-WNW and NEN-SWS, the former component being the predominating one.

Hitotsubashi.

The Duplex Pendulum indicated the max. 2a of about 5.0mm, the principal directions being *E–W* and *NEN–SWS*.

Eqke No. 44. Feb. 2, 1888 ; 2.23.46 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 109s.

Direction. *E–W*.

Max. H. M. 0.7mm (period = 1.4s).

Character. Gentle.

Hongo.

The motion was chiefly in the *EW* component, the max. 2a being 0.2mm. There was no vertical motion.

Eqke No. 45. Feb. 2, 1888 ; 3.0.14 p.m.

A tremor, observed only at the *Cent. Met. Observatory*.

Eqke No. 46. Feb. 2, 1888 ; 3.41.27 p.m.

Observation at the *Cent. Met. Observatory*.

Duration. 45s.

Direction. *WSW–ENE*.

Max. H. M. 3.8mm (period = 2.4s).

Max. V. M. ———

Character. Gentle.

Remark. The earthquake, which began with small movements, became active the at 42nds there being 12 principal vibrations during the next 14s. The motion decreased gradually from the 74th second.

Hongo.

The motion was moderately large and sharp, the character being on the whole similar to that of eqke No. 43.

Horizontal motion. The amplitude was nearly equal in the two components.

Duration = 115s (*EW* component) ;

,, = 85s (*NS* ,,).

The earlier part of the EW component consisted entirely of ripples, while the corresponding portion of the NS component consisted of slow large vibrations superposed with ripples; so that the ground moved during the first 15 seconds sensibly in the NS direction and thereafter more in the EW direction. The average period of the ripples was 0.19s in the EW and 0.16s in the NS component.

Max. $2a = 0.5$mm, $T_0 = 0.57$; $V = 2.8^{mm}/_{s}$, $A = 31^{mm}/_{s.^2}$

After the disappearance of the superposed ripples the vibrations in each component became regular, the average period being 0.81s in the EW and 0.48s in the NS component.

Vertical motion. Duration = 26s.

The motion consisted of very small vibrations, whose average period was 0.23s.

Max. $2a = 0.06$mm, $T_0 = 0.4$s; $V = 0.5^{mm}/_{s}$, $A = 8^{mm}/_{s.^2}$

Duplex Pendulum. The motion was chiefly in the EW and NS directions.

Eqke No. 47. Feb. 3, 1888; 2.31.56 p.m.

This was a very small tremor, recorded by the Duplex Pendulum at Hongo.

Eqke No. 48. Feb. 5, 1888; 0.50.56 a.m.

This was a very extensive earthquake, whose origin was near the Tsugaru strait; Tōkyō being on the edge of the shaken area.

Observation at the *Cent. Met. Observatory*:—

Duration. 60s.

Direction. *SW-NE.*

Max. H. M. 1.6mm (period = 2.1s).

Character. Gentle.

Area of disturbance. The land area of disturbance was 9000 sq. *ri* and extended from Hokkaido on the north down to Kazusa and Musashi on the south, including the following 23 provinces:—Oshima, Shiribeshi,

Iburi, Hidaka, Tokachi, Kushiro, Nemuro, Ishikari, Kitami (south eastern part), Teshiwo (southern portion), Mutsu, Rikuchu, Ugo, Uzen, Rikuzen, Iwaki, Hitachi, Shimosa, Iwashiro, (eastern part), Shimotsuke, Kotsuke (south-eastern portion), Musashi (eastern portion), Kazusa (northern part). The shock was felt *strong* in Mutsu(northeastern part), Oshima (eastern portion), Iburi (south-eastern portion), Hidaka(southern part) and Tokachi (south-western portion). No severe damage, however, was produced.

Hitotsubashi.

Duration=120s. There was no vertical motion.

The motion began gently with extremely small undulations, whose period was, however, not shorter than that in the principal portion. In the *NS* component, the chief motion appeared about 40s after the commencement.

Max. 2a=1.0mm, T_0=0.57s ; V=5.5mm/s, A=60mm/s.²

The average period, deduced from 68 vibrations in the *NS* component, was 0.45s.

The Duplex Pendulum indicated motion chiefly in the *NS* and *EW* directions.

Hongo.

The amplitude of motion was nearly equal in the two horizontal components. The period of vibration was as follows : —

EW component........Aver. period=0.84s (deduced from 19 vibrations) ;

NS component........Aver. period=0.47s (deduced from 23 vibrations).

Eqke No. 49. Feb. 10, 1888 ; 3.26.55 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 10s.

Direction. *NE-SW.*

Max. H. M. Small.

Max. V. M. ——

Character. Quick.

Hitotsubashi.

Duration = 25s. The motion consisted of very small slow undulations which were nearly equal in the two horizontal components. No vertical motion.

Max. $2a = 0.25$mm, $T_0 = 0.6$s ; $V = 1.3^{mm}/_{s}$, $A = 13^{mm}/_{s^2}$

The period of vibration was as follows : —

EW compononent .... Aver. period = 0.78s (deduced from 3 vibrations) ;

NS component .... Aver. period = 0.7s (deduced from 16 vibrations).

The Duplex Pendulum gave a very simple diagram, the motion being chiefly in the *NS* direction and to a slight amount in the *EW* direction.

Eqke No. 50. Feb. 10, 1888 ; 36.8.7 p.m.

Observation at the *Cent. Met. Observatory.*

Duration. 12s

Direction. *E-W.*

Max. H.M. Very small.

Hilostubashi.

Duration = 30s. The motion was chiefly in the *NS* direction, there being no vertical component.

Max. $2a = 0.25$ mm, $T_0 = 0.62$s ; $V = 1.3^{mm}/_{s}$, $A = 12.9^{mm}/_{s^2}$

The movements were very small and constant in period, the average value, deduced from 21 vibrations in the *NS* component, was 0.70s.

The Duplex Pendulum at Hitotsubashi gave a very simple diagram, which consisted of only a few movements in the *NS* direction.

Hongo.

Duration = 35s. The motion was very small, there being no vertical component.

Max. $2a = 0.15$ mm, $T_0 = 0.5$s ; $V = 0.94$ $^{mm}/_{s}$, $A = 12$ $^{mm}/_{s^2}$

The Duplex Pendulum at Hongo indicated movements chiefly in the EW direction.

Eqke No. 51. Feb. 11,1888; 3.33.56 p.m.

Recorded at the *Cent. Met. Observatory* as a *slight* shock.

Hongo.

Duration $=40s$. The motion, which was very small, occurred equally in the two horizontal components.

Max. $2a=0.1$ mm, $T_0=0.5s$; $V=0.6$ mm/s, $A=7.9$ mm/s.²

Eqke No 52. Feb. 13,1888; 11.33.44 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 25s.

Direction. *N-S.*

Max. H.M. Small.

Character. Gentle.

Hitotsubashi.

Duration $=40s$. The motion consisted of very small vibrations, whose average period, deduced from 12 vibrations in the NS component, was 0.52s.

Max. $2a=0.1$ mm, $T_0=0.45s$; $V=0.7$ mm/s, $A=10$mm/s.²

The Duplex Pendulum at Hitotsubashi indicated movements chiefly in the NS direction.

Hongo.

The diagram indicated very small movements.

Eqke No. 53. Feb. 15,1888; 3.43.38 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 30s.

Direction. *E-W.*

Max. H.M. Very small.

Character. Gentle.

Hitotsubashi and *Hongo.* Motion was very small.

Eqke No. 54. Feb. 17,1888 ; 0.16.17 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 50s.

Direction. *E-W.*

Max. H.M. Very small.

Character. Gentle.

This earthquake was not felt at *Hongo.*

Eqke No. 55. Feb. 18,1888 ; 6.13.45 p.m.

Observation at the *Cent. Met. Observatory* :—

Direction. *E-W.*

Max. H.M. Very small.

Character. Gentle.

Eqke No. 56. Feb. 22,1888 ; 10.24.43 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 90s.

Direction. *N–S.*

Max. H.M. 0.7mm (period = 3.2s)

Character. Gentle.

Hitotsubashi.

Duration = 120s. This was a moderate earthquake, the motion being at first somewhat greater in the *NS* than in the *EW* component.

Max. 2a = 0.45 mm, $T_0 = 0.78$s ; $V = 1.8$ mm/s, $A = 14$ mm/s.²

The average period in the *NS* component was 0.67s.

Hongo.

Duration = 100s. The motion was chiefly in the *NS* direction, there being no vertical motion.

Max. 2a = 0.24 mm, $T_0 = 0.79$s ; $V = 0.95$ mm/s, $A = 7.5$mm/s.²

The average period in the *NS* component was 0.74s.

Eqke No. 57. Feb. 22,1888 ; 11.10.50 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 10s.
Direction. *N–S.*
Max. H.M Very small.
Character. Gentle.

Eqke No. 58. Feb. 24,1888 ; 2.7.6 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. ——
Direction. *E-W.*
Max. H.M. Very small.
Character. Gentle.

Hitotsubashi.

Duration = 120s. The motion, which consisted of regular vibrations of constant period, was almost entirely in the *EW* direction, there being no vertical component.

Max. $2a=0.4$ mm, $T_0=0.84$s ; $V=1.5$ mm/s, $A=11.$ mm/s²

The avearge period, deduced from 37 vibrations in the *EW* component, was 0.85s.

Hongo.

Duration = 25s. This was a very small earthquake, the motion being almost entirely in the *NS* component. There was no vertical motion.

Max. $2a=0.12$ mm, $T_0=0.52$s ; $V=0.73$ mm/s, $A=9$mm/s²

The average period, deduced from 30 vibrations in the *NS* component, was 0.46s.

Eqke No. 59. March 1,1888 ; 3.30.15 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 88s.
Direction. *WSW—ENE.*
Max. H.M. Small.
Character. Gentle.

Hitotsubashi.

Duration = 100s. The motion, which was very small, was chiefly in the EW component, there being no vertical component.

Max. $2a = 0.4$ mm, $T_0 = 0.7s$; $V = 1.8\ ^{mm}/_{s}$, $A = 16\ ^{mm}/_{s.}$?

The average period, deduced from 25 vibrations in the EW component, was 0.71s.

Eqke No. 60. March 1,1888 ; 9.54.12 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 30s.

Direction. *N–S.*

Max. H.M. Small.

Max. V. M. ——

Character. Quick.

Hongo.

Horizontal motion. Duration = 16s.

The motion consisted of a series of extremely small quick vibrations, and was almost entirely in the EW component, the average period being 0.23s.

Max. $2a = 0.1$mm.

Vertical motion. The duration was very short.

The motion was very small, the average period being 0.17s.

Eqke No. 61. March 9,1888 ; 4.54.16 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 25s.

Direction. *NWN—SES.*

Max. H.M. 0.4 mm (period = 0.2s).

Max. V.M. ——

Character. Quick.

Remark. For the first 3s, the vibrations were quick. Then followed suddenly the most active part of the motion, which lasted 2s. Thereafter the vibrations became again abruptly small.

Hitotsubashi.

On this occasion, the motion at *Hitotsubashi* was smaller than that at *Hongo*.

Horizontal motion. Duration (obscured). The motion was chiefly in the *EW* component.

Max. 2a = 0.32 mm, $T_o = 0.86$s ; $V = 1.2$ mm/s, $A = 9$ mm/s.²

Vertical motion. The motion was very slight.

Hongo.

Horizontal motion. Duration = 30s.

The motion occurred equally in the two horizontal components and consisted of very quick vibrations. The *principal portion* lasted only for a few seconds, the subsequent motion being much smaller.

Max. 2a = 0.32 mm, $T_o = 0.3$s ; $V = 3.4$ mm/s, $A = 72$ mm/s.²

In the *EW* component, the average period was at first 0.18s, but towards the end 0.37s.

In the *NS* component, the period remained constant, the average value being 0.19s.

Vertical motion. Duration = 12s. The vertical motion existed in a comparatively large amount. The following maximum motion occurred at the commencement.

Max. 2a = 0.07 mm, $T_o = 0.26$s ; $V = 0.9$ mm/s, $A = 2.1$ mm/s.²

The average period of vibration was at first 0.12s and towards the end 0.16s.

In this case, there was apparently parallelism between the horizontal and vertical components, both being maximum at the commencement and also of nearly the same period.

Eqke No. 62. March 16,1888 ; 6.43.0 a.m.

Hitotsubashi

Horizontal motion. Duration = 100s. The motion, which was almost entirely in the *EW* component, began very gently and remained nearly constant in amplitude through a considerable interval of time.

Max. 2a = 0.4 mm, $T_o = 0.74$s ; $V = 1.7$mm/s, $A = 15$ mm/s.²

The period remained constant, the average value, deduced from 38

vibrations in the *EW* component, being 0.85s.

Vertical motion. There were only very slight traces of vertical motion.

Hongo.

Horizontal motion. Duration = 70s. The motion, which was very small, occurred equally in the two horizontal components.

Vertical motion. The motion was very slight.

Eqke No. 63. March 17,1888 ; 7.55.36 p.m.

A tremor, observed only at the *Cent. Met. Observatory.*

Eqke No. 64. April 1,1888 ; 6.17.8 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. ——

Max. H.M. V ry small.

Character. Gentle.

Eqke No. 65. April 5,1888 ; 2.30.29 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 120s.

Direction. *SE–NW.*

Max. H.M. 1.2 mm (period = 0.7s).

Max. V.M. 0.5 mm (period = 0.3s).

Character. Quick.

Remark. The earthquake began with horizontal and vertical tremors which lasted for 10s. Then the motion became suddenly great, remaining active for the next 30s. This earthquake, notwithstanding the smallness of amplitude, was felt violently, probably because it was accompanied by quick period vertical vibrations throughout the whole duration.

Area of disturbance. The total land area of disturbance was 4060 sq. *ri* and extended over the following 16 provinces :— Hitachi, Shimosa,

Shimotsuke, Kazusa, Musashi, Awa, Sagami Kōtsuke, Izu, Kai, Iwaki, Iwashiro (southern part), Rikuzen (southern portion), Echigo (southern portion), Shinano (eastern part), Suruga (eastern part). The motion was *strong* within an area of 690 sq. *ri* which included Hitachi (central portion), Shimosa (north-western part), Musashi (north-eastern part), Kotsuke (eastern portion), Shimotsuke (southern part). The shock was felt very violently in the Makabe District of Hitachi, where workmen on house roofs had difficulty in supporting themselves on account of sudden powerful vertical movements. Again, in the Kawachi District of Shimotsuke the motion was very violent, and *shoji* and other sliding doors were almost thrown down. The directions of motion in the strongly shaken area were mostly *SE-NW* or *S-N*. No severe damage was produced.

Hitotsubashi.

Horizontal motion. Duration = 150s.

The motion at *Hitotsubashi*, which was somewhat greater in the *EW* than in the *NS* component, consisted of regular vibrations not so much superposed with ripples as at *Hongo*. The *NS* component began with preliminary tremor, which lasted for 3s. The *EW* component, however, was already well pronounced at the commencement, so that the ground moved at first chiefly in the *EW* direction.

The motion consisted of a great number of vibrations whose amplitude remained nearly equal for a considerable interval of time, and whose period remained constant till the very end. The following maximum vibration, nearly in the *EW* direction, took place 18 seconds after the commencement :—

Max. 2a = 2.0 mm, $T_0 = 0.77$s ; $V = 8.2$ mm/s, $A = 67$ mm/s.²

The relation between the 2a and T of the horizontal vibrations is given in the next table :—

HITOTSUBASHI ; HORIZONTAL MOTION.

2a (mm)		T (sec.)	
2.0 2.0 1.9 1.8 1.8 1.8	1.9(mean)	0.77 0.77 0.77 0.92 0.84 0.71	0.80(mean)
1.6 1.5 1.5 1.4 1.4 1.3	1.45(mean)	0.84 0.70 0.84 0.69 0.84 0.73	0.77(mean)
1.25 1.25 1.2 1.2 1.15 1.15	1.2(mean)	0.84 0.80 0.70 0.71 0.69 0.65	0.73(mean)
1.1 1.1 1.05 1.05 1.05	1.07(mean)	0.69 0.77 0.92 0.72 0.84	0.73(mean)

2a (mm)		T (sec.)	
1.0 1.0 1.0 1.0 1.0 0.95 0.95 0.93	0.98 (mean)	0.80 0.63 0.84 0.69 0.80 0.69 0.73 0.84	0.75 (mean)
0.9 0.9 0.9 0.9 0.85 0.83 0.75 0.75 0.75 0.5 0.5	0.78 (mean)	0.71 0.84 0.71 0.84 0.65 0.70 0.65 0.84 0.80 0.63 0.65	0.73 (mean)

The measurement given in the above table has been taken from the first 50 s of the diagram. Towards the very end, the average period, deduced from 10 vibrations, was 0.70s.

The relation between the 2a and *T* given above relates to the *resultant* vibrations, that is to say, the 2a was obtained in each case by compounding the corresponding displacements in the two directions. If we take the two components separately, the result is as follows :--

In the *EW* component, the average period, deduced from 150 vibrations during the first two minutes was 0.75 s, while that deduced from 14 vibrations at the very end was 0.77s. In the *NS* component, the corresponding average periods, deduced respectively from 83 and 8 vibrations, were 0.77s and 0.80s. These values are nearly the same as those given in the above table, which give a mean period of 0.76s.

Vertical motion. Duration = 50s.

The vertical motion began with preliminary tremor whose duration was nearly equal to that in the *NS* component, the motion being well pronounced during the first 20s. The following maximum vibration occurred about 11s after the commencement, simultaneous with a large horizontal displacement in the *EW* direction :—

Max. 2a = 0.6 mm, $T_o = 0.65s$; $V = 2.9$ mm/s, $A = 28$ mm/s.²

The relation between the 2a and *T* of the vertical motion was as follows.

HITOTSUBASHI : VERTICAL MOTION.

2a (mm)		T (sec.)		2a (mm.)		T (sec.)	
0.6		0.65		0.21		0.51	
0.5		0.6		0.21		0.57	
0.36		0.43		0.21		0.60	
0.33		0.44		0.14		0.48	
0.3		0.46		0.14	0.13(mean)	0.51	0.49(mean)
0.3	0.3(mean)	0.57	0.49(mean)	0.14		0.46	
0.26		0.43		very small		0.34	
0.21		0.40		”		0.37	
0.21		0.43					
0.21		0.51					

Thus in this earthquake the period of the vertical vibrations, which remained on the whole constant, was much slower than is usually the case.

Hongo.

Horizontal motion. Duration = 110s.

The motion began with preliminary tremor of a very short duration. There was no single prominent maximum, but the earthquake consisted at first essentially of quick sharp vibrations or ripples of an average period of 0.2s superposed on slow undulations ; the ripples subsequently disappearing. The motion was somewhat larger in the *NS* than in the *EW* component.

Max. 2a = 1.4 mm, $T_o = 0.71s$, *Direction* nearly *NEN*, $V = 6.2$ mm/s, $A = 55$ mm/s.²

The two largest ripples were as follows :—

(1) $2a = 0.54$ mm, $T = 0.2s$; $V = 8.5^{mm}/_{s}$, $A = 270^{mm}/_{s^2}$.

(2) $2a = 0.74$ mm, $T = 0.24s$; $V = 9.7$ „ , $A = 250$ „

The ripples lasted for 25s.

The average period of the undulations, which became regular after the disappearance of the ripples, was as follows :—

EW component ...... 0.57s (deduced from 50 vibrations);

NS „ ...... 0.78s („ „ 49 „).

I may here note that the earthquake of March 9th 1888 was moderately severe, but the minute ripples, which constituted its commencement and principal portion, were far smaller than those occurring in the earlier portion of the present earthquake. It may, therefore, be supposed that the severity of shocks at *Hongo* is largely due to ripples.

Vertical motion. Duration = 25s.

The vertical motion, which was active from the commencement, consisted of nearly equal minute vibrations whose period was approximately constant and had an average value of about 0.2s. There was no single prominent wave.

Max. $2a = 0.14$mm, $T_0 = 0.24s$; $V = 1.8^{mm}/_{s}$, $A = 48^{mm}/_{s^2}$

The origin of the earthquake was nearly due north of Tokyo. From the analysis of the diagrams at *Hongo* and *Hitotsubashi* given above it seems that the vibrations were not distinctly divided into the *normal* and the *transverse* waves.

Eqke No. 66. April 8, 1888; 2.22.32 p.m.

A tremor observed only at the *Cent. Met. Observatory.*

Eqke No. 67. April 7, 1888;——

Hitotsubashi.

Duration = 40s. The motion which consisted of perfectly regular vibrations was chiefly in the *EW* direction, there being no vertical component.

Max. $2a = 0.38$mm, $T_0 = 0.83s$; $V = 1.4^{mm}/_{s}$, $A = 10^{mm}/_{s^2}$

The average period deduced from 25 vibrations in the *EW* component was 0.78s.

Hitotsubashi.

The average period, deduced from 20 vibrations in the *EW* component, was 0.79s.

Eqke No. 68. April 16, 1888 : 11.6.43 p.m.

A tremor observed only at the *Cent. Met. Observatory.*

Eqke No. 69. April 29, 1888 ; 10.0.33 a.m.

Observation at the *Cent. Met. Observatory* :

Duration = 8m.

Direction. *SE-NW.*

Max. H.M. 5.6mm (period = 0.8s).

Max. V.M. 1.5mm (period = 0.6s).

Character. Quick.

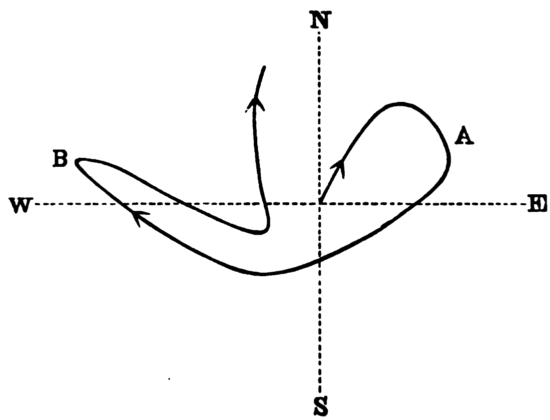
Remark. The earthquake began with horizontal and vertical tremors, which lasted for 12s, when the maximum horizontal motion suddenly took place. The maximum vertical motion occurred at the 17th second, the total duration being 1m 14s. The horizontal motion remained more or less active for the first 3 minutes.

Area of disturbance. The total land area of disturbance, which was unusually large, was 5080 sq. *ri* and extended from the Pacific to the coast of Echigo, including the following 20 provinces :—Musashi, Sagami, Izu, Suruga, Totomi, Kai, Kotsuke, Shimotsuke, Hitachi, Kazusa, Awa, Shimosa, Iwaki, Iwashiro, Shinano, Rikuzen(southern portion), Uzen (southern portion), Echigo (central part), Mikawa (eastern part). The area of *strong motion* was 1930 sq. *ri* and included the 12 provinces of Musashi, Sagami, Izu, Suruga(eastern part), Kai(eastern part), Shinano (eastern portion), Kozuke (south-eastern part, Shimotsuke (southern part), Hitachi (southern part), Shimosa (western part), Kazusa (western portion), Awa (western part). Within this area some slight damage was produced, such as cracks and subsidence of embankments(Nasu District,

Shimotsuke); cracks of walls(Utsunomiya and Shimo-tsuga District, Shimotsuke); overturning of furnitures(Tokyo and Kita-Saitama District, Musashi); overflowing of liquids (Kuraki District, Musashi; Minami-Saku District, Shinano; Izu; Haga District, Shimotsuke); stopping of pendulum clocks (Izu; Minami-Saku District, Shinano.)

Horizontal motion. Duration = 4m.

The earthquake began with preliminary tremor, which lasted for about 15s during which the motion in the *EW* direction was much



greater than that in the *NS* direction just as was the case with the earthquake of April 5,1881. The earlier portion of the shaking was superposed with traces of ripples which were insignificant. At the termination of the preliminary tremor the following maximum motion suddenly took place:—

Max. 2a = 6.2mm, *Direction* from E to W, $T_c = 1.4s$; $V = 14^{mm}/_{s}$, $A = 63^{mm}/_{s^2}$.

The motion of the earth's particle at the commencement of the principal portion represented in the annexed diagram, where AB is the maximum motion) was nearly similar at *Hongo* and *Hitotsubashi.* The character of motion was, however, altogether different at these two places. Thus, at *Hongo* the principal motion consisted of a single initial maximum vibration, followd by ripples; while at *Hitotsubashi* it consisted of a series of large vibrations of period much slower than at *Hongo.*

The relation between 2a and T of the horizontal motion is given in the next table.—

HITOTSUBASHI : HORIZONTAL MOTION.

2a (mm)		T (sec.)		2a (mm)		T (sec.)	
6.2 5.3 4.8	5.5(mean)	1.4 1.1 1.1	1.2(mean)	2.9 2.9 2.8 2.8 2.8	2.8(mean)	0.9 0.83 1.1 0.75 0.9	0.9(mean)
4.5 4.1 3.9	4.2(mean)	0.83 1.1 1.1	1.0(mean)				
3.6 3.5 3.3 3.3	3.4(mean)	1.1 0.98 0.9 1.1	1.0(mean)	2.5 2.5 2.5 2.3	2.5(mean)	0.84 1.1 0.9 1.1	0.99(mean)
3.3 3.0 3.0 3.0 3.0 3.0	3.0(mean)	0.94 1.1 0.98 0.98 0.83 0.9	0.96(mean)	2.0 2.0 1.8 1.6 1.3	1.7(mean)	0.75 0.75 0.83 0.68 0.83	0.77(mean)

The measurement in the above table is taken from the earlier portion of the diagram. In the very end portion, the average period deduced from 24 vibrations was 0.86s.

Taking each of the horizontal components separately, the numbers of vibrations and the average period during the successive 16.5s were as follows :—

EW component.			*NS* component.		
Number of vibrations during 16.5s.	Average period (sec.).		Number of vibrations during 16.5s.	Average period(sec.).	
18	0.92	0.95(mean)	18	0.92	0.93(mean)
17	0.97		19	0.87	
18	0.92		17	0.97	
17	0.97				
17	0.97				
17	0.97				
18	0.92				
17	0.97				
18	0.92				
18	0.92				

The average period of vibration was thus constant.

Vertical motion. Duration = 3m.

The vertical motion existed in a considerable amount but was rather slow in period, the character being very different from that at *Hongo*. Like the horizontal motion, it began with preliminary tremor which lasted for about 15s, followed by large displacements exactly simultaneous with the horizontal components. The maximum vertical motion occurred slightly later than the maximum horizontal motion:—

Max. 2a = 0.75 mm, $T_0 = 1.0$s; $V = 2.4$ mm/s, $A = 15.$ mm/s.²

The vertical vibrations were very slow, their period being at first identical with that of the horizontal. The period lengthened towards the end, the amplitude remaining, however, sensibly constant. Thus the average period was, during the first 30 seconds, 9.4s, while at the end it was 1.7s.

Hongo.

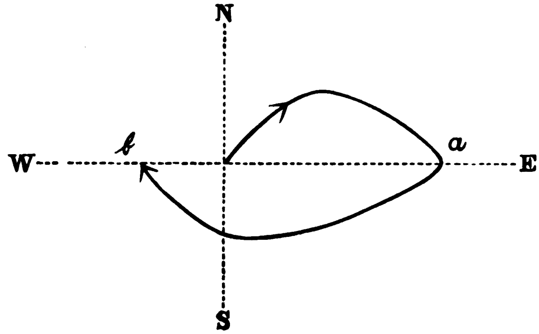
Horizontal motion.

Duration = 130s ...... *EW* component.

„ = 180 ...... *NS* „

The earthquake began as usual with preliminary tremor which lasted for about 4s, when there occurred suddenly the following maximum vibration:—

Max. 2a = 4.0 mm, *Direction* from *E* to *W*, $T_0 = 1.0$s; $V = 13$ mm/s, $A = 80$ mm/s.²



The initial movement in the principal portion is illustrated in the

annexed diagram, *ab* being the maximum displacement. The latter was the only large wave in the whole earthquake, the rest of the principal portion consisting of quick vibrations or ripples. In the end portion, large slow undulations appeared. Although the greatest displacement occurred in the *EW* component, yet otherwise the motion was greater in the *NS* component; this being the case especially towards the end of the earthquake.

The maximum of the ripples, which lasted for the first 35s, was the following:—

Max. $2a=1.1$ mm, $T_0=0.23$s : $V=15^{mm}/_{s}$, $A=400^{mm}/_{s^2}$.

The average period of the ripples was as follows.—

EW component . . Aver. period $=0.18$s (deduced from 49 vibrations).
NS „ . . Aver. period $=0.18$s („ „ 77 „).

After the disappearance of the ripples, the motion became simpler and consisted of regular vibrations. The numbers of the latter in the *NS* component during the successive 22s were as follows:—17,19,17,19, 18 . . giving a mean period of 1.2s. Traces of similar waves were also to be recognized in the earlier portion. The period of vibration in the *NS* component remained constant till the very end. The average period deduced from 30 vibrations in the end portion of the *EW* component was 0.73s. The maximum of the vibrations in the end portion was the following:—

$2a=2$ mm, $T_0=1.3$ s ; $V=4.8^{mm}/_{s}$, $A=23^{mm}/_{s^2}$.

The relation between the 2a and T of the vibrations after the 70th second is given in the following table:—

HONGO : HORIZONTAL MOTION.

NS component.				*EW* component.			
2a (mm)		T (sec.)		2a (mm)	Number of vibrations.	Average T (sec.)	
1.4		1.9					
1.2		1.3					
1.0		1.3					
0.8		1.1		0.94	1	1.0	
0.8	0.9(mean)	2.0	1.4(mean)	0.6	1	0.91	
0.7		1.0		0.6	1	1.3	
0.7		1.4		0.5	1	0.72	
0.7		1.3		0.4	1	0.78	
0.7		1.3		very small	4	0.51	
0.6		0.98		,,	4	0.57	
0.6		1.06		,,	3	0.52	0.7s
0.6	0.6(mean)	1.4	1.2(mean)	,,	7	0.47	
0.6		1.2		,,	3	0.52	
0.6		1.1		,,	4	0.58	
0.6		1.5		,,	5	0.55	
0.4		1.2		,,	5	0.69	
0.4		0.76		,,	3	0.69	
0.4		1.5		,,	2	0.72	
0.4		1.2					
0.4		1.1					
0.3	0.32 (mean)	1.1	1.07 (mean)				
0.3		1.1					
0.3		1.3					
0.2		0.64					
0.2		0.85					
0.2		1.0					

The average period deduced from 23 vibrations in the very end portion of the *NS* component was 0.94s.

Vertical motion. Duration = 30s.

The vertical motion, which was active during the first 32 seconds, was irregular and consisted of some very small vibrations mixed with comparatively large undulations, the character being similar to that of the horizontal motion. In this case, therefore, the vertical motion might be due, partly at least, to the vertical component of the normal or transverse motion and not a purely surface motion.

There was no prominent wave in the vertical component which

might correspond to the maximum horizontal vibration, though otherwise the active movements took place, in general, simultaneously in the two components.

Max. $2a=0.25$mm, $T_0=0.31$s ; $V=2.5^{mm}/_{s}$, $A=50^{mm}/_{s.^2}$

Towards the end, the vibrations became regular and had an average period of 0.2s.

The relation between the 2a and T of the vertical vibrations is given in the following table.

HONGO : VERTICAL MOTION.

2a (mm)		T (sec.)		2a (mm)	Number of vibrations.	Average T (sec.)	
0.33		0.46					
0.3	0.3 (mean)	0.46	0.43 (mean)				
0.3		0.40		very small	1	0.11	
0.25		0.38		”	1	0.08	
0.21		0.27		”	1	0.14	
0.20		0.36		”	1	0.13	
0.20		0.36		”	1	0.18	
0.19	0.19 (mean)	0.30	0.31 (mean)	”	1	0.16	
0.19		0.34		”	1	0.19	
0.18		0.27		”	3	0.21	0.19 (mean)
0.16		0.30		”	1	0.23	
0.13		0.23		”	4	0.20	
0.13		0.21		”	3	0.27	
0.13		0.24		”	4	0.22	
0.13		0.26		”	4	0.16	
0.13		0.21		”	8	0.15	
0.1	0.10 (mean)	0.19	0.21 (mean)	”	18	0.20	
0.09		0.23					
0.08		0.15					
0.08		0.23					
0.06		0.19					
0.06		0.19					
0.06		0.15					

Eqke No. 70. April 30, 1888 : 5.41.38 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. ——

Direction. *E-W.*

Max. H.M. Very small.

Character. Gentle.

Eqke No. 71. April 27, 1888; 8.34.34 a.m.

Observation at the *Cent. Met. Observatory*:—

Duration. 2m.

Direction. *SW—NE.*

Max. H.M. 0.2mm (period = 1.5s).

Character. Gentle.

Hitotsubashi.

A small earthquake, whose motion consisted entirely of regular gentle vibrations, there being no vertical component. Duration = 110s.

Max. $2a = 0.35$ mm, $T_0 = 0.91$s; $V = 1.2$ mm/s, $A = 8$ mm/s.²

The average period was as follows:—

EW component......0.87s (deduced from 27 vibrations).
NS ,, ...0.89s (,, ,, 11 ,,).

Eqke No. 72. May 5, 1888; 8.52.24 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 73. May 8, 1888; 4.7.56 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 74. May 8, 1888; 4.51.41 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 75. May 10, 1888; 10.12.0 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 76. May 13, 1888; 4.51.52 a.m.

Observation at the *Cent. Met. Observatory*:—

Duration. 10s

Direction. *NW-SE.*

Max. H.M. 0.2 mm (period = 0.5s)

Character. Quick.

Hitotsubashi.

A small and gentle earthquake, whose motion was almost entirely in the *EW* direction; there being no vertical motion. Duration = 60s.

Max.2a = 0.35 mm, $T_0 = 0.75$s; $V = 1.6$ mm/s, $A = 14$ mm/s.²

The average period, deduced from 30 vibrations in the *EW* component, was 0.76s.

The motion presented a series of maxima which occurred at the commencement and at 5.5s, 10.2s, 14.9s, 19.2s, and 23.9s, respectively after the latter; the average interval being 4.8s.

Eqke No. 77. May 13, 1888 : 11.17.41 p.m.

a tremor observed at the *Cent. Met. Observatory.*

Eqke No. 78. May 22, 1888 : 6.9.20 p.m.

Observation at the *Cent. Met. Observatory*:—

Duration. 4m 30s.

Direction. *ESE-WNW.*

Max. H.M. 1.5 mm (period = 2.6s (?))

Max. V.M. 0.2 mm (period = 0.7s).

Character. Gentle.

Hitotsubashi.

Horizontal motion. Duration = 4m.

The preliminary tremor lasted for about 10s and consisted of vibrations, whose period was nearly equal to that in the succeding portions.

Max.2a = 2.2 mm, $T_0 = 0.97$s; $V = 7.1$ mm/s, $A = 46.1$ mm/s.²

The average period deduced from 40 vibrations during the first 1m of the *EW* component, was 0.83s, that deduced from 34 vibrations in the end portion of the same component being also 0.84s.

Vertical motion. Duration = about 2m.

The duration of the preliminary tremor was equal to that of the horizontal.

Max. $2a=0.4$mm, $T_0=0.70$s ; $V=1.8$ mm/s, $A=16$ mm/s.²

The period was unusually long, the average value deduced from 17 vibrations, being 0.64s.

Hongo.

Horizontal motion. Duration $=140$s.

The motion, which was greater in the *EW* than in the *NS* component, was at first a little irregular, but soon became regular.

Max. $2a=0.74$ mm, $T_0=0.78$s ; $V=3$ mm/s, $A=25$ mm/s.²

The maximum was, however, not prominently large, there being a great number of vibrations of nearly equal amplitude. The average period of vibration, after the disappearance of ripples was as follows:—

EW component......0.54s(deduced from 58 vibrations) ;

NS „ ......0.85s(„ „ 26 „).

Vertical motion. Duration $=20$s.

This began with small waves.

Max. $2a=0.1$ mm, $T_0=0.37$s ; $V=0.9$ mm/s, $A=14.4$ mm/s.²

The average period deduced from 17 vibrations was 0.18s.

Eqke No. 79. May 24, 1888 ; 9.35.37 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 60s.

Direction. *E—W.*

Max. H.M. Small.

Character. Gentle.

Eqke No. 80. May 24, 1888 ; 11.45.5 a.m.

A tremor, which was felt at *Hongo*, but did not start the machines.

Eqke No. 81. May 26, 1888 ; 6.17.14 p.m.

A tremor. The seismographs at *Hitotsubashi* recorded very slight movements.

Eqke No. 82. May 27, 1888 ; 7.5.9 p.m.

Observed as a tremor at the *Cent. Met. Observatory.*

Hitotsubashi.

Duration=60s. This was a very small earthquake, whose motion was chiefly in the *EW* direction and consisted of regular gentle vibrations of a constant period; there being no vertical component. The maximum occurred at the commencement :—

Max. 2a=0.25mm, T_0=0.71s ; V=1.1 mm/s, A=10 mm/s².

The average period, deduced from 28 vibrations in the *EW* component, was 0.74s.

Eqke No. 83. June 3, 1888; 7.53.8 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 3m.

Direction. *WNW-ESE.*

Max. H.M. Small.

Character. Gentle.

Hitotsubashi.

Horizontal motion. Duration=180s.

The motion, which was greater in the *EW* than in the *NS* component, was irregular at first but soon became regular. There was no prominently large displacement, the motion being made up of a series of vibrations of nearly constant period, the amplitude decreasing very gradually.

Max. 2a=1.8mm, T_0=0.94s ; V=6 mm/s, A=40 mm/s².

The average period, deduced from 21 vibrations in the principal portion of the *EW* component, was 0.80s; that deduced from 48 vibrations in the end portion of the same component was 0.86s.

Vertical motion. Duration=25s.

The vertical motion, the duration of whose preliminary tremor was equal so that of the horizontal, consisted of slow vibrations, whose average period deduced from 7 largest vibrations was 0.63s.

Max.2a=0.2mm, T_0=0.62s ; V=0.5 mm/s, A=2.6mm/s².

Eqke No. 84. June 12, 1888 ; 9.6.27 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 20s.

Direction. *NWN–SES.*

Max. H.M. 0.4mm (period=1.2s)

Character. Gentle.

Hitotsubashi.

Duration=100s. There was no vertical component. The motion which was at first slightly superposed with ripples soon became regular and constant in period.

Max.2a=0.3 mm, T_0= 0.88s ; V= 1.1mm/s, A=8.0mm/s².

The average period deduced from 40 vibrations was 0.78s.

Hongo.

Horizontal motion. Duration=60s.

The motion occurred equally in the two components. At first the vibrations were very quick, the average period being 0.23s. Towards the end, the vibrations became very slow; the average period deduced from 9 vibrations being 2.0s.

Max.2a=0.16mm, T_0=0.22s ; V=2.3 mm/s, A=66 mm/s².

Vertical motion. Duration=10s.

The vertical motion, whose maximum occurred at the commencement, was well pronounced in comparison to the preliminary tremor of the horizontal.

The period of the vertical motion was identical with that of the small movements in the earlier portion of the horizontal; there being during the first 2.9s interval 14 vibrations in the horizontal and also exactly the same number in the vertical component. Thus it may be supposed that the vertical motion and the horizontal ripples are related to one another, and are possibly components of surface waves; the earth particle describing a small elliptical orbit, whose vertical axis is comparable in magnitude to the horizontal.

Max.2a=0.06mm, T_0=0.23s ; V=0.9 mm/s, A=23 mm/s².

The motion consisted of small regular waves, whose average period was 0.26s.

Eqke No. 85. June 15, 1888 ; 0.21.25 a.m.

A tremor observed at the *Cent. Met. Observatory* :—

Eqke No. 86. June 18, 1888 ; 2.20.31 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 100s.

Direction. *SE-NW.*

Max. H. M. 0.3mm (period= 0.8s).

Character. Quick.

Hitotsubashi.

Horizontal motion. Duration=120s.

As usual with earthquakes of a moderate intensity, this consisted of a great number of vibrations nearly constant in amplitude and period, none being prominently large. The motion was much greater in the *EW* than in the *NS* component.

Max. 2a=1.0 mm, T_o=0.70 s ; V=4.5 mm/s, A=41 mm/s.²

The average period deduced from 58 vibrations was 0.76s.

Vertical motion. Only doubtful traces.

Hongo.

Horizontal motion. Duration=70s.

The character of motion was much similar to that of the earthquake of June 12, 1888. The motion began with small irregular vibrations, but afterwards became lengthened in period.

Max.2a=0.2mm, T_o=0.6s ; V=0.52 mm/s, A=2.7 mm/s².

In the *EW* component, the ripples had an average period of 0.42s, these being superposed on slower undulations of an average period of 1.3s. In the *NS* component, the corresponding average periods were erspectively 0.46s and 1.2s ; towards the very end, the waves had an average period of 2.1s.

Eqke No. 87. June 18, 1888 ; 3.17.6 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 88. June 18, 1888 ; 9.59.14 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 89. June 19, 1888 ; 6.29.57 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 20s.

Direction. *E-W.*

Max. H.M. 0.2 mm (period = 0.8s)

Character. Quick.

Eqke No. 90. June 22, 1888 ; 7.6.25 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 91. June 24, 1888 ; 11.8.20 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 10s.

Direction. *E-W.*

Max. H.M. Small.

Character. Quick.

Eqke No. 92. July 2,1888 ; 4.51.56. a.m.

Observed as a tremor at the *Cent. Met. Observatory.*

Hitotsubashi.

Duration = 30s. The motion which was very small, was almost entirely in the *EW* direction, there being no vertical component.

Max. 2a = 0.25 mm, $T_0 = 0.57$s ; $V = 1.4$ mm/s, $A = 16$ mm/s.²

Eqke No. 93. July 7,1888 ; 9.37.37 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 180s.

Direction. *E-W.*

Max. H.M. Small.

Character. Gentle.

Hitotsubashi.

Duration = 80s. The motion, which consisted of slow regular vibra-

Observation at the *Cent. Met. Observatory* :—

Duration. 90s.

Direction. *E–W*.

Max. H.M. 0.2 mm(period=0.8s).

Character. Quick.

Hitotsubashi.

Duration=100s. A small and gentle earthquake, whose motion was almost entirely in the *EW* direction, there being no vertical component. There were several alternations of maximum and minimum groups.

Max. 2a=0.83 mm, T_0=0.72s ; V=3.6 mm/s, A=31 mm/s.²

The average period of vibration was as follows:—

EW component......0.74s (deduced from 24 vibrations),

NS „ ......0.93s („ „ 10 „).

It will be observed that this earthquake was similar to some of the preceding. The periods in the two horizontal components were, as often happens, not alike.

Eqke No. 102. Aug.11, 1888; 9.31.42 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 103. Aug.12, 1888 ; 11.42.27 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 180s.

Direction. *SWS—NEN*.

Max. H.M. 0.4 mm(period=1.2s).

Character. Gentle.

Hitotsubashi.

Duration=3 m. The earthquake, which began very gently, gradually attained the full amplitude and then remained nearly of the same size through a considerable time interval. The motion was much greater in the *EW* than in the *NS* direction, there being no vertical component.

Max. 2a=1.1 mm, T_0=0.81s ; V=4.3 mm/s, A=34 mm/s.²

The average period, deduced from 117 vibrations in the *EW* compo-

nent, was 0.78s.

Hongo.

Duration = about 3 m. No vertical motion.

Max. 2a = 0.5 mm.

Eqke No. 104. Aug. 17,1888 ; 3.49.50 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 70s.

Direction. *E-W.*

Max. H.M. 0.2 mm (period = 1.0s)

Character. Gentle.

Eqke No. 105. Aug. 18,1888 ; 1.22.0 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Hitotsubashi.

Duration = 100s. No vertical motion.

Max. 2a = 0.2 mm, $T_0 = 0.88$s ; $V = 0.7$ mm/s, $A = 5$ mm/s.²

The average period, deduced from 27 vibrations, was 0.79s.

Hongo.

The motion was very small.

Eqke No. 106. Aug. 19,1888 ; 9.19.26 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 107. Aug. 19,1888 ; 11.47.25 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 108. Sept. 2,1888 ; 5.45.0 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 30 s.

Direction. *E-W.*

Max.H.M. Very small.

Character. Gentle.

Observed as a tremor at the *Cent. Met. Observatory.*

Hitotsubashi.

The motion was very slight.

Eqke No. 122. Oct. 20,1888 ; 6.15.16 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 2m.

Direction. *NEN-SWS.*

Max. H.M. 1.2mm(period=0.5s)

Max. V.M. 0.5mm(period=0.5s)

Character. Quick.

Remark. The earthquake began with quick horizontal and vertical movements. There were three prominent vertical vibrations, of which the first was the maximum. The horizontal motion was active during the first 20s.

Hitotsubashi.

Horizontal motion. Duration=120s.

The earthquake began with preliminary tremor, which lasted for 7s, when the motion became suddenly active, the amplitude being much larger in the *EW* than in the *NS* component.

Max. 2a=0.7 mm, T_0=0.66s ; V=3.3 mm/s, A=31 mm/s.²

The motion was of maximum intensity immediately after the preliminary tremor. The average period, deduced from 32 vibrations, was 0.78s.

Vertical motion. Duration=40s.

The vertical motion, whose preliminary tremor consisted of very small movements, became active simultaneously with the horizontal.

Max. 2a=0.18 mm, T_0=0.38s ; V=1.5 mm/s, A=25mm/s.²

This maximum occurred not exactly at the same moment as the maximum horizontal motion.

Hongo.

Horizontal motion. Duration=70s. The motion, which occurred equally in the two horizontal components, commenced with the following maximum :—

Max. $2a=0.6$mm, Direction *S*.

A second maximum, which occurred later on, was the following :—

$2a=0.34$ mm, $T_0=0.55$s ; $V=1.9 \mathrm{mm/s}$, $A=21 \mathrm{mm/s^2}$

The vibrations were at first irregular, but soon became regular. The average period deduced from 11 well defined vibrations was 0.52s.

Vertical motion. Duration $=20$s. The motion, which was active during the first 10s, consisted of small vibrations, whose average period deduced from 8 vibrations was 0.28s. There was no well defined large vibration.

Max. $2a=0.13$mm, $T_0=0.38$s ; $V=1.1 \mathrm{mm/s}$, $A=20 \mathrm{mm/s^2}$

Eqke No. 123. Nov. 2,1888 ; 1.48.1 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 60s.

Direction. *E-W.*

Max. H.M. 0.3mm(period = 0.8s).

Character. Quick.

Hitotsubashi.

Horizontal motion. Duration $=160$s. This was a moderate earthquake, whose motion was much greater in the *EW* than in the *NS* component and which consisted of perfectly regular vibrations.

The preliminary tremor lasted for 10s and consisted of small slow vibrations of an average period of 0.58s. This was suddenly followed by large movements.

Max. $2a=1.2$mm, Direction *SW*, $T_0=0.77$s ; $V=4.9 \mathrm{mm/s}$, $A=40 \mathrm{mm/s^2}$

The average period deduced from 38 vibrations in the *EW* component was 0.71s.

Vertical motion. Duration $=30$s. The motion began very gradually. The following maximum occurred a little later than the horizontal maximum :—

Max. $2a=0.2$mm, $T_0=0.4$s ; $V=1.6 \mathrm{mm/s}$, $A=25.6 \mathrm{mm/s^2}$

Hongo.

Horizontal motion. Duration = 40s. The motion began with the following maximum :—

Max. 2a = 0.54mm, Direction *SW*.

In the subsequent portion the motion was small (Max. 2a = 0.1 mm) and seemed to be merely the residual of the above initial movement.

In the earlier part of the *EW* component, the average period was 0.21s, that in the corresponding part of the *NS* component being 0.23s.

Vertical motion. Duration = 20s. The motion was very small; the average period deduced from 15 vibrations was 0.17s.

Eqke No. 124. Nov. 3,1888 ; 0.51.14 a.m

Observation at the *Cent. Met. Observatory* :—

Duration.	90s.
Direction.	*E-W*.
Max. H.M.	0.3mm(period = 0.5s).
Max. V.M.	Small.
Character.	Quick.

Hongo.

Duration = 20s. No vertical motion.

Max. 2a = 0.14 mm, $T_0 = 0.34$s ; $V = 1.3$ mm/s, $A = 2.4$ mm/s.²

The motion consisted of irregular vibrations.

Eqke No. 125. Nov. 3,1888 ; 8.13.33 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	4m 30s.
Direction.	*SW-NE*.
Max. H.M.	1.9mm(period = 0.4s).
Max. V.M.	0.5mm(period = 0.4s .
Character.	Quick.

Remark. The preliminary tremor lasted for 7s, when both the vertical and the horizontal components became large. The maximum vertical vibration occurred at the 16th second, the motion remaining active

for the next 3s. The maximum horizontal motion occurred at the 10th second, the motion remaining active for the next 20s.

(This earthquake which was moderately severe was unfortunately not recorded at *Hitotsubashi* and *Hongo*.)

Eqke No. 126. Nov. 5,1888 ; 4.22.55 a.m.

Observed as a tremor at the *Cent. Met. Observatory.*

Hitotsubashi.

Duration = 60s. The motion was almost entirely in the *EW* component.

Max. 2a = 0.25mm, T_o = 0.82s ; V = 0.96 mm/s, A = 7.1mm/s.²

The average period deduced from 18 vibrations was 0.77s.

Eqke No. 127. Nov. 6,1888 ; 4.38.37 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 180s.

Max. H.M. 0.2mm(period = 2.2s)

Character. Gentle.

Eqke No. 128. Nov. 7,1888 ; 10.27.34 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 240 s.

Direction. *E–W.*

Max. H.M. 0.5mm(period = 3.5s (?)).

Character. Gentle

Hitotsubashi.

Duration = 250s. No vertical motion.

This was a very small earthquake, the motion consisting of slow vibrations.

Max. 2a = 0.36mm, T_o = 2.8s ; V = 0.4 mm/s, A = 0.9 mm/s.²

Eqke No. 129. Nov. 10,1888 ; 1.37.44 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 90s.

Direction. *WNW-ESE.*

Max. H.M. 0.3mm(period = 1.8s).

Character. Gentle.

Hitotsubashi.

Duration = 2m. No vertical motion.

The motion, which was chiefly in the *EW* direction, consisted of small regular vibrations.

Max. 2a = 0.75 mm, T_0 = 0.87s ; V = 2.7 mm/s, A = 19.2 mm/s.²

The average period of vibration was as follwos :—

EW component ......0.85s(deduced from 34 vibrations),

NS „ ......0.65s(„ „ 13 „).

Eqke No. 130. Nov. 16,1888 ; 0.42.49 a.m.

Observed as a tremor at the *Cent. Met. Observatory.*—

Hitotsubashi.

Duration = 60s. No vertical motion.

The motion, which was entirely in the *EW* direction, was of maximum amplitude at the commencement, the subsequent portion presenting alternations of maximum epochs.

Max. 2a = 0.4 mm, T_0 = 0.95s ; V = 1.3 mm/s, A = 8.5 mm/s.²

The average period, deduced from 26 vibrations in the *EW* component, was 0.9s

Eqke No 131. Nov. 20,1888 ; 0.53. 29 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 150s.

Direction. *E-W.*

Max. H.M. 0.2mm(period = 0.9s).

Character. Gentle.

Hitotsubashi.

Duration = 3m. The duration was very long in comparison to the amplitude, which remained nearly constant during a considerable interval of time. The motion was chiefly in the *EW* direction, there being

no vertical motion.

Max. 2a = 0.75mm, T_0 = 0.75s ; V = 3.1 $^{mm}/_{s}$, A = 25.3 $^{mm}/_{s.^2}$

The average period, deduced from 17 vibrations in the *EW* component, was 0.77s.

Hongo.

The motion was very small.

Eqke No. 132. Nov. 22,1888 ; 1.27.43 p.m.

Observed as a tremor at the *Cent. Met. Observatory.*

Hitotsubashi.

Duration = 170s. The motion was chiefly in the *EW* direction, there being no vertical component.

Max. 2a = 0.63 mm, T_0 = 0.85s ; V = 2.3 $^{mm}/_{s}$, A = 16.5 $^{mm}/_{s.^2}$

The average period, deduced from 29 vibrations in the *EW* component, was 0.8s.

Eqke No. 133. Nov. 23,1888 ; 5.13.30 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 134. Nov. 24,1888 ; 2.3.23 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	240s.
Direction.	*NW–SE.*
Max. H.M.	0.4mm (period = 1.4s).
Character.	Gentle.

Eqke No. 135. Nov. 25,1888 ; 4.[illegible]0.15 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	15s.
Direction.	*E–W.*
Max. H.M.	0.2mm (period = 0.5s).
Character.	Quick.

Hitotsubashi.

Duration = 45s. The motion, which was entirely in the *EW* direction, consisted of perfectly regular small vibrations, with several alternations of maximum and minimum groups.

Max.2a = 0.5mm, $T_0 = 0.92s$; $V = 1.7$ mm/s, $A = 12$ mm/s.^{2}

The average period deduced from 18 vibrations was 0.94s.

Hongo.

Horizontal motion. Duration = 15s. The motion consisted of very small vibrations which were shiefly in the *NS* direction.

Max.2a = 0.08mm, $T_0 = 0.26s$.

The average period was about 0.26s.

Vertical motion. Duration = 15s. The motion was comparatively active and consisted of vibrations of an average period of 0.18s.

Max.2a = 0.38mm, $T_0 = 0.18s$; $V = 0.7$ mm/s, $A = 2.3$ mm/s.^{2}

Eqke No. 136. Dec. 1,1888 ;——

Hitotsubashi.

The motion consisted of slow gentle movements of a long duration, chiefly in the *NS* direction.

Eqke No. 137. Dec. 3,1888 ; 0.24.47 p.m.

Observation at the *Cent. Mét. Observatory* :—

Duration. 120s.

Direction. *SE–NW.*

Max. H.M. 0.2mm (period = 1.8s).

Character. Gentle.

Hitotsubashi.

Duration = 120s. The earthquake, which was chiefly in the *EW* direction, consisted of a series of vibrations whose amplitude remained nearly constant. There was no vertical motion.

Max. 2a = 0.63mm, $T_0 = 0.79s$; $V = 2.5$mm/s, $A = 20$mm/s.^{2}

The average period, deduced from 28 vibrations in the *EW* component, was 0.77s.

Eqke No. 138. Dec. 6,1888 ; 7.27.42 a.m.

Observed as a tremor at the *Cent. Met. Observatory.*

Hitostubashi.

Duration = 80s. This was a very small earthquake, whose motion occurred equally in the two horizontal components, there being no vertical vibration.

Max. $2a = 0.17$mm, $T_0 = 0.68$s ; $V = 0.79^{mm}/_{s}$, $A = 7.3^{mm}/_{s^2}$

The average period, deduced from 27 vibrations in the *EW* component, was 0.75s.

Hongo.

Motion was very small.

Eqke No. 139. Dec. 16,1888 ; 4.19.3 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	20s.
Direction.	*N–S.*
Max. H.M.	Small.
Character.	Gentle.

Hongo.

Horizontal motion. Duration = ? The motion consisted of a single prominent displacement, followed by small vibrations, the earthquake having been probably caused by some sudden blow, which acted only for a moment. The residual motion might be the free vibration of the ground. The *EW* component was much smaller than the *NS*. The numbers of vibrations in the latter component during the eight successive 10 seconds intervals after the greatest movement were :— 16, 18, 21, 19, 21, 21, 20, 20 ; the period being thus somewhat longer at the commencement, where the amplitude was also greater. Towards the end the period became constant.

Average period (NS) = 0.5s.

Vertical motion. Duration = ? The vertical motion consisted of vibrations, whose period remained constant and had an average value of 0.2s. It may be remarked that the period was very nearly equal to

the average period (0.24s) of the small ripples in the horizontal motion, whose duration was also nearly equal to that of the vertical motion.

Eqke No. 140. Dec. 21,1888 ;——.

Observed as a tremor at *Hitotsubashi* and *Hongo.*

Eqke No. 141. Dec. 28,1888 ; 3.28.4 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 35s.

Direction. *E–W.*

Max. H.M. 0.2 mm (period = 1.7s).

Character. Gentle.

Hitotsubashi.

Duration = 60s. A very small earthquake, whose motion was greater in the *EW* than in the *NS* direction, there being no vertical motion.

Max.2a = 0.2mm, $T_0 = 0.8s$; $V = 0.8$ mm/s, $A = 6.1$ mm/s².

The average period, deduced from 8 vibrations in the *EW* component, was 0.86s.

Eqke No. 142. Jan. 1,1889 ; 3.4.50 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 12s.

Direction. *SW–NE.*

Max. H.M. 0.5mm (period = 0.3s).

Max. V.M. Small.

Character. Quick.

Hitotsubashi.

Duration = 70s. This was a small earthquake, whose motion was chiefly in the *EW* direction, there being no vertical component. The maximum vibration occurred at the commencement.

Max.2a = 0.38mm, Direction *E*, $T_0 = 0.87s$; $V = 1.4$ mm/s, $A = 9.9$ mm/s².

The vibrations which followed the maximum rapidly decreased, the average period being as follows :—

EW component ......0.81s (deduced from 42 vibrations);

NS „ ......0.84s („ „ 15 „).

Hongo.

The motion was immeasurably small.

Eqke No. 143. Jan. 1,1888; 7.5.30 p.m.

Observation at the *Cent. Met. Observatory*:—

Duration.	120s.
Direction.	*SW-NE.*
Max. H.M.	1.1mm (period=0.1s (?)).
Max. V.M.	0.5mm (period=0.3s).
Character.	Quick.

Remark. The earthquake began with preliminary tremor, which lasted for 6s, and which were chiefly in the *EW* direction. Thereafter the motion became large in all the three components, executing 80 active vibrations during the next 10 seconds interval.

Area of disturbance. The earthquake originated in the boundary districts of Hitachi and Musashi and extended on the north to a radial distance of 60 *ri*, while on the south and the east it reached the sea shores. The land area of disturbance was 3430 sq. *ri* and included the following 16 provinces: Musashi, Shimosa, Kazusa, Awa, Hitachi, Shimotsuke, Kotsuke, Sagami, Kai, Izu (northern part), Suruga (eastern part), Shinano (eastern portion), Echigo (southern portion), Iwashiro (southern part), Iwaki (southern part), Rikuzen (southern portion). The area of strong motion was about 700 sq. *ri*, and extended over the following 6 provinces: Musashi (eastern part), Shimosa (western part), Hitachi (southern part), Shimotsuke (southern portion), Kotsuke (south-eastern portion), and Sagami (north-eastern portion). Within the latter area, sharp vertical motion was generally felt. In Tokyo the shock was strong enough to cause overturning of furnitures, etc. At Mito (province of Hitachi) some articles were thrown down from shelves, and at Kawachi District (province of Shimotsuke) *shoji* or paper covered sliding doors were almost thrown out ot the grooves.

Eqke No. 144. Jan. 3,1889; 7.58.6 a.m.

Observation at the *Cent. Met. Observatory*:—

Duration.	120s.
Direction.	*E-W.*
Max. H.M.	0.8mm (period=1.5s).
Character.	Gentle.

Eqke No. 145. Jan. 5,1889;———

Hongo.

Duration=120s. The motion, which was irregular, consisted of gentle vibrations.

Max. 2a=0.4 mm, $T_0=1.4$s; $V=0.9$ mm/s, $A=4.0$mm/s.²

Eqke No. 146. Jan. 7,1889; ———

Hitotsubashi.

Duration=40s. The motion, which consisted of extremely small vibrations of a constant period, was chiefly in the *EW* direction, there being no vertical component.

Max. 2a=0.1mm, $T_0=0.82$s; $V=0.4$ mm/s, $A=2.9$ mm/s.²

The average period was as follows:—

EW component......0.81s (deduced from 24 vibrations),

NS „ ......0.86s („ „ 12 „).

Eqke No. 147. Jan. 12,1889; 8.34.3 p.m.

A tremor observed at the *Cent. Met. Observatory*:—

Eqke. No. 148. Jan. 13,1889;———

Hitotsubashi.

Duration=60s. A very small earthquake, whose motion was chiefly in the *EW* direction, there being no vertical component.

The preliminary tremor, whose duration was short, consisted of vibrations of the same period as in the subsequent portion. The vibrations in the *NS* component were small and ill defined.

Max. 2a = 0.38 mm, Direction E-W, $T_0 = 0.47$s ; $V = 2.5$ mm/s.
$A = 34$ mm/s.²

Eqke No. 149. Jan. 27, 1889 ; 2.28.47 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 150. Jan. 29, 1889 ;——

Hitotsubashi.

Duration = 60s. This was a small earthquake, whose motion was chiefly in the *EW* direction, and which began very gradually. At about 8s from the commencement, the motion reached its full amplitude thence gradually decreasing.

Max.2a = 0.38mm, $T_0 = 0.56$s ; $V = 2.1$ mm/s, $A = 23.9$ mm/s.²

The average period in the *EW* component was as follows :— 16 vibrations in the earlier part, whose 2a varied between 0.4mm and mm and had a mean value of 0.3 mm, had an average period of 0.6s ; while the 17 vibrations of small 2a in the end portion gave an average period of 0.55s.

Eqke No. 151. Feb. 5, 1889 ; 2.27.39. p.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	5s.
Direction.	*N–S.*
Max. H.M.	Small.

Eqke No. 152. Feb. 9, 1889 ; 7.41.38 a.m.

Observation at the *Cent. Met. Observatory.*

Duration.	10s.
Direction.	*N–S.*
Max. H.M.	Small.
Character.	Quick.

Eqke. No. 153. Feb. 15, 1889 ; 5.14.3 a.m.

A tremor observed at the *Cent. Met. Observatory.*

[E]qke No. 154. Feb. 18, 1889 ; 6.9.32 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	6m 12s.
Direction.	*NW–SE.*
Max. H.M.	20.3 mm (period = 2.2s).
Max. V.M.	3.7 mm (period = 0.6s).
Character.	Quick.

Remark. The earthquake began with small sharp horizontal [a]nd vertical vibrations. At the 15th second a sudden horizontal motion [o]f 6 mm took place in the direction *SW–NE*, followed by 10 large [v]ibrations which together lasted for 5 seconds, when the maximum dis[p]lacement took place. The vertical motion became active also at the [1]5th second, its maximum occurring 5 seconds later than the horizontal [m]aximum. The horizontal motion was more or less active during the [fi]rst 5m 19s, and the vertical motion for the first 2m 4s.

Area of disturbance. The total land area of disturbance was 5750 [s]q. *ri*, and included the following 21 provinces :—Musashi, Sagami, Awa, [K]azusa, Shimosa, Hitachi, Shimotsuke, Kotsuke, Kai, Suruga, Izu, Totomi, Shinano, Iwashiro, Iwaki, Rikuzen (south-eastern part), Uzen (south-eastern part), Echigo (central part), Mikawa (nearly whole of the province), Owari (northern part), Mino (eastern part). The area of *strong* motion was 1390 sq. *ri* and extended over the following 11 provinces :—Musashi, Sagami, Izu, Awa, Kazusa, Shimosa, Hitachi, (southern part), Shimotsuke (southern part, Kotsuke (southern portion), Kai (eastern part), Suruga (eastern part). The shock was felt with a great violence within an area of 300 sq. *ri*, which extended over the five provinces of Sagami (eastern part), Musashi (south-eastern portion), Shimosa (south-western portion), Kazusa and Awa. Within the latter area, houses were damaged, furnitures overturned, etc. Thus in Tokyo, *dozo* (Japanese godowns) had plasters shaken down ; walls were cracked ; tomb stones and *ishidoro* (Japanese stone lanterns) overturned ; furnitures overthrown ; pendulum clocks stopped ; liquids thrown out ; etc. In Yokohama, some houses were damaged. In Aiko District, province of

Sagami, *dozo* were cracked. Along the sea shore of Tsurugi-zaki in the same province the shock was also very strong and some houses were damaged. In Awa, pendulum clocks were stopped, and waters thrown out from vessels which were about $\frac{7}{10}$ full. In the Mota District, province of Kazusa, house walls were cracked, articles overthrown, and liquids thrown out by about 30% from vessels filled with them. In the Nagara District of the same province, people generally ran out of doors, and liquids were thrown out of vessels.

In the Kawachi District, province of Shimotsuke, house walls were cracked, bottles overturned, pendulum clocks stopped. In the Haga District of the same province, pendulum clocks were stopped and liquids thrown out. In the Naka-Koma District, province of Kai, some articles were overturned............This earthquake originated like some other strong ones probably at the southern extremity of the Tokyo Bay. But it was for the first time since the winter of 1884, when the system of the earthquake observation in Japan was organized, that the disturbance extended to such great distances towards North-West. The damage produced, however, was not very severe.

The direction of motion in the meizo-seismal area was as follows: *SE-NW* or *E-W* on the western shore of the Tokyo Bay, *E-W* and *SE-NW* on the eastern, and mostly *N-S* on the northern shore.

Hongo.

Horizontal motion. Duration = 8m. The earthquake began with preliminary tremor, which lasted for about 11s and consisted of quick small vibrations. These latter were already moderatley strong, (max. $2a = 0.8$ mm), being as large as the movements in the earthquake of March 9, 1888.

After the termination of the preliminary tremor, the motion became suddenly great in the two horizontal components, there being five prominent displacements, the first of which was from *S* to *N*, and the second of which was nearly from *E* to *W*. The succeding vibrations, which were far smaller, were quick in period. After about 20s from the commencement of the earthquake, the superposed ripples disappear-

ed and the vibrations became slow in period. The five principal displacements above referred to were as follows:—

1st displacement:—

$2a=1.7$ mm, Direction from S to N, $T_o=0.41s$; $V=13$ mm/s, $A=200$ mm/s.^{2}

2nd displacement:—

$2a=2.1$ mm, Direction $S\,72°\,W$, $T_o=0.64s$; $V=10.3$ mm/s, $A=100$ mm/s.^{2}

3rd displacement:—

$2a=3.2$ mm, Direction $S59°E$, $T_o=0.54s$; $V=18.6$ mm/s, $A=220$ mm/s.^{2}

4th displacement:—

$2a=6.0$ mm, Direction $S57°\,W$. $T_o=0.58s$; $V=32.5$ mm/s, $A=350$ mm/s.^{2}

5th displacement:—

$2a=7.2$ mm, Direction $S48°E$, $T_o=1.3s$; $V=17.4$ mm/s, $A=84$ mm/s.^{2}

In the earlier part of the earthquake, the vibrations were very irregular and complex and it was not possible to see any definite relation between the 2a and T. The measurement in the following table has been taken from the horizontal component after the disappearance of the ripples.

HONGO : HORIZONTAL MOTION.

2a (mm)		T (sec.)		2a (mm)		T (sec.)	
4.2		2.0					
4.0		2.4		1.3		1.7	
3.1		2.2		1.2		1.7	
3.0	3.1(mean)	1.6	2.0(mean)	1.1		1.3	
2.6		1.9		1.1		1.0	
2.4		2.4		0.9		0.97	
2.2		1.8		0.9		0.97	
1.9		1.6		0.9		0.97	
1.9		1.5		0.9		1.4	
1.9		1.7		0.7	0.55	0.70	1.07
1.8		1.2		0.7	(mean)	1.3	(mean)
1.8		1.6		0.7		1.4	
1.8		1.9		0.6		0.72	
1.7	1.7 (mean)	1.5	1.6 (mean)	0.6		1.1	
1.6		1.9		0.6		1.1	
1.6		1.9		0.56		0.82	
1.6		1.7		0.5		0.87	
1.5		1.1		0.34		0.58	
1.5		1.7		0.3		0.70	
1.4		1.1					

Vertical motion. Duration = 220s.

The preliminary tremor lasted for about 9s, during which the maximum motion was 0.3 mm. Then followed two large displacements superposed with irregular ripples. The succeeding vibrations were somewhat smaller but quick in period, so that the character of motion were exactly similar to that of the horizontal. From the 22nd second the vibrations became slower in period.

Max. 2a = 1.0 mm, $T_0 = 0.96$ s ; $V = 3.3$ mm/s, $A = 21.4$ mm/s².

The maximum motion occurred 2.4s earlier than the large horizontal vibration; the most active portion of the vertical component also ending 2.4s earlier than the corresponding portion of the horizontal.

In this case, the motion was, unlike that in small earthquakes, not simple and regular, but was irregular and superposed with ripples.

The relation between the 2a and T is given in the following table.—

HONGO ; VERTICAL MOTION.

2a (mm)		T (sec.)		2a (mm)		T (sec.)	
1.1		0.92					
1.0		0.96					
0.8		1.06					
0.8		0.67					
0.8		0.67		0.38		0.39	
0.8	0.83(mean)	0.87	0.84(mean)	0.38		0.68	
0.8		1.06		0.31		0.33	
0.75		0.69		0.31		0.40	
0.75		0.77		0.29	0.26	0.48	0.41
0.75		0.58		0.28	(mean)	0.39	(mean)
0.75		0.96		0.28		0.39	
0.63		0.39		0.13		0.48	
0.63		0.77		0.13		0.19	
0.63		0.87		0.13		0.34	
0.63		0.68					
0.56		0.48					
0.56	0.55(mean)	0.77	1.59(mean)				
0.5		0.39					
0.5		0.68					
0.5		0.55					
0.44		0.53					
0.44		0.39					

The average period deduced from 30 vibrations in the end portion was 0.39s.

Eqke No. 155. Feb.18 ,1889 ; 6.27.45 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 120s.

Direction *SW–NE.*

Max. H.M. 0.2mm.

Area of disturbance. The total land area of disturbance was 1320 sq. *ri*, and extended over the following 10 provinces ; Musashi, Sagami (eastern part , Kazusa western part), Shimosa (western part), Hitachi (south-western portion), Shimotsuke (southern part), Kotsuke (southern part), Shinano (eastern portion), Kai (eastern portion), Suruga north-eastern portion). The motion was generally weak.

Hitotsubashi.

Duration$=$100s. The motion was almost entirely in the *EW* direction, there being no vertical component.

Max. 2a$=$0.3mm, $T_0=0.65$s ; $V=1.4\,\mathrm{mm}/_{s}$, $A=14.0\,\mathrm{mm}/_{s^2}$.

The period remained exactly constant, the average value deduced from 30 vibrations being 0.74s.

Eqke No. 156. Feb. 18,1889 ; 7.48.52 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 120s.

Direction. *E-W.*

Max. H.M. Small.

The area of disturbance was nearly identical with that of the preceding (*Eqke No. 155*), the motion having been felt *weakly* or *slightly*.

Eqke No. 157. Feb. 18,1889 ; 8.2.0 a.m.

Observed as a tremor at the *Cent. Met. Observatory.*

The area of disturbance was limited to the vicinity of Tokyo.

Eqke No. 158. Feb. 18,1889 ; 10.10.56 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 30s.

Direction. *SE-NW.*

Max. H.M. Small.

The land area of disturbance was 1050 sq. *ri* and extended more in the *N-S* direction than those of earthquakes Nos. 155 and 156, including the following 8 provinces :—Musashi, Sagami (eastern part), Kai (north-eastern portion), Kotsuke(south-eastern part), Shimotsuke (south-western portion), Hitachi (south-western portion), Shimosa (western part), Kazusa (western portion).

The shork was felt *weakly.*

Eqke No. 159. Feb. 19,1889 ; 2.57.43 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 15s.

Direction. *N–S.*

Max. H.M. Small.

Character. Gentle.

Eqke No. 160. Feb. 20,1889 ; 9.19.37 p.m.

Observed as a tremor at the *Cent. Met. Observatory.*

Eqke No. 161. Feb. 21,1889 ; 5.52.21 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 15s.

Direction. *E–W.*

Max. H.M. Small.

Character. Sharp.

Hitotsubashi.

Duration = 25s. A very small earthquake, whose motion was entirely in the *EW* direction, there being no vertical component.

Max. 2a = 0.13mm, T_o = 0.51s ; V = 0.8 mm/s, A = 9.9 mm/s.^{2}

The average period, deduced from 21 vibrations in the *EW* component, was 0.62s.

Eqke No. 162. Feb. 21,1889 ; 8.19.23 a.m.

Observation at the *Cent. Met. Observatory* : —

Duration = 20s.

Direction. *N–S.*

Max. H.M. Small.

Character. Gentle.

Eqke No. 163. Feb. 21,1889 ; 11.1.4 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 30s.

Max. H.M. Very small.

Character. Gentle.

Eqke No. 164. Feb. 21,1889 ; 9.27.52 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 15s.

Direction. *N–S.*

Max. H.M. Small.

Character. Gentle.

Eqke No. 165. Feb. 23,1889 ; 11.27.21 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 13s.

Direction. *N–S.*

Max. H.M. Small.

Character. Gentle.

Eqke No. 166. March 3,1889 ; 4.35.19 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 30s.

Direction. *N–S.*

Max. H.M. 0.2mm (period = 0.6s).

Eqke No. 167. March 4,1889 ; 7.24.25 a.m.

Observed as a tremor at the *Cent. Met. Observatory.*

Hitotsubashi.

Duration = 80s. This was a small earthquake, whose motion was almost entirely in the *EW* direction, there being no vertical component. The maximum vibration occurred at the commencement, the succeeding vibrations presenting alternations of maximum and minimum groups.

Max. 2a = 0.25 mm, $T_0 = 0.65$s ; $V = 1.2$ mm/s, $A = 11.7$mm/s.²

The average period, deduced from 44 vibrations in the *EW* component, was 0.69s.

Hongo.

Duration=20s. The motion, which was extremely small, occurred equally in the two horizontal directions there being no vertical component.

Eqke No. 168. March 18,1889 ; 6.41.12 a.m.

Observation at the *Cent. Met. Observatory* :—

Direction. *N-S.*

Max. H.M. Small.

Eqke No. 169. March 21,1889 ; 6.9.23 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 170. March 26,1889 ; 2.41.48 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 171. March 28,1889 ; 1.20.10 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 90s.

Direction. *ESE-WNW.*

Max. H.M. 4.1 mm (period=0.6s).

Max. V.M. 0.6 mm (period=0.5s).

Character. Quick.

Remark. The horizontal preliminary tremor lasted for 4s, when the maximum horizontal motion suddenly took place. The vertical motion also became active at the 4th second from the start, its maximum having occurred 4s later than the horizontal maximum.

Hongo.

Horizontal motion. Duration=80s. The motion consisted principally of quick vibrations, which were irregular at first but became regular later on ; there being no prominent movement. The motion was maximum at the commencement and active only during the first 20s, so that the intensity decreased rapidly. The amplitude was greater in the *EW* component ; the motion at the start being principally in the *EW* direction.

Max. $2a=0.7$ mm, $T_0=0.25s$: $V=8.8^{mm}/_{s}$, $A=221^{mm}/_{s^2}$

Another vibration was as follows :—

Max. $2a=0.5$mm, $T'_0=0.21s$; $V=7.5^{mm}/_{s}$, $A=224^{mm}/_{s^2}$

The average period of the quick vibrations in the earlier part of the earthquake was as follows :—

EW component......0.27s(deduced from 40 vibrations),

NS „ ......0.29s(„ „ 22 „).

Towards the end the vibrations were slow and had the following average periods :—

EW component......1.2s (deduced from 6 vibrations),

NS „ ......0.75s („ „ 46 „).

Vertical motion. Duration = 60s. The motion was maximum at the commencement and remained active during the first 25s. The period was at first quick, but became slow towards the end.

Max. $2a=0.23$ mm, $T_0=0.44s$; $V=1.6^{mm}/_{s}$, $A=23.5^{mm}/_{s^2}$

The average period was at first 0.36s (deduced from 22 vibrations), but in the end portion 0.65s (deduced from 10 vibrations).

Eqke No. 172. March 28,1889 ; 10.22.55 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 75s.

Direction. *SE-NW.*

Max. H.M. 0.5 mm (period = 0.5s).

Max. V.M. Small.

Character. Gentle.

Remark. The motion was active from the commencement, there being 50 similar vibrations during the first 23s. The vertical motion was very small and lasted for 40s.

Hongo.

Horizontal motion. Duration = 100s.

The motion began very gently with small slow vibrations.

Max. $2a=0.8$mm, $T_0=0.69s$; $V=3.6^{mm}/_{s}$, $A=33.2^{mm}/_{s^2}$

The average period was as follows :—

EW component......0.75s (deduced from 48 vibrations),

NS ,, ...1.0s (,, ,, 36 ,,).

Vertical motion. Duration=40s. The motion consisted of small slow vibrations.

Max. 2a=0.2mm, T_0=0.93s; V=0.7mm/s, A=4.6mm/s²

The average period deduced from 17 vibrations was 0.66s.

Eqke No. 173. March 28,1889 ; 7.18.23 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 20s.

Direction. *E–W.*

Max. H.M. 0.2 mm (period=0.2s).

Character. Quick.

Remark. The preliminary tremor lasted for 5s, when suddenly the maximum movement took place, the motion remaining active for the next 5s.

Eqke No. 174. March 31,1889 ; 6.42.15 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 240s.

Direction. *SES–NWN.*

Max. H.M. 3.8mm (period=2.5s).

Max. V.M. 0.2mm (period=0.6s).

Character. Gentle.

Remark. The motion was at first very small, the horizontal movement becoming active at the 5th second and reaching the maximum at the 25th second. The vertical maximum occurred at the 15th second, the motion lasting altogether for about 25s.

Hongo.

Horizontal motion. Duration=200s. The motion consisted of slow undulations, superposed with some small ripples.

Max. 2a=1.2 mm, T_0=1.13s ; V=3.3mm/s, A=190mm/s².

The average period was as follows :—

EW component......1.24s (deduced from 16 vibrations),

NS „ ......1.12s („ „ 40 „).

Vertical motion. Duration = 65s. The motion was at first irregular and there was no prominently large movement.

Max. 2a = 1.4mm, $T_0 = 0.82$s; $V = 5.4^{mm}/_{s}$, $A = 41.0^{mm}/_{s^2}$

The quick vibrations at the commencement had an average period of 0.12s. Towards the end the average period was 0.83s.

Eqke No. 175. March 31,1889; 8.13.3 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 176. March 31,1889; 5.59.42 p.m.

Observation at the *Cent. Met. Observatory*:—

Duration.	120s.
Direction.	*SW-NE.*
Max. H.M.	1.2mm (period = 0.7s).
Max. V.M.	Very small.
Character.	Gentle.

Remark. The earthquake began with very small movements, the maximum horizontal motion occurring at the 30th second. For the next 60 seconds the motion was more or less active. The vertical motion lasted for 50s.

Hongo.

Horizontal motion. Duration = 240s. The motion, which began very gradually, was more in the *EW* direction and consisted of slow vibrations. The following well defined movement took place a few seconds from the commencement:—

Max. 2a = 0.6mm, $T = 1.43$s; $V = 1.3\ ^{mm}/_{s}$, $A = 5.8^{mm}/_{s^2}$

For the next 7.8s during which the motion was irregular, small ripples were superposed on slow vibrations; the average period being 0.49s. The motion then became gradually regular and increased in amplitude, till the following maximum took place at the 80th second:—

Max. 2a = 1.1mm, $T_0 = 2.1$s; $V = 1.6\ ^{mm}/_{s}$, $A = 4.9\ ^{mm}/_{s^2}$

The vibrations remained nearly constant for a considerable length of time.

The average period of vibration was as follows :—

EW component......2.32s (deduced from 24 vibrations),

NS „ ......1.19s („ „ 58 „).

Vertical motion. Duration = 60s. The motion was very small and consisted of slow vibrations.

Max. 2a = 0.01 mm, $T_0 = 0.51$s ; V = small, A = small.

The average period deduced from 13 vibrations was 0.54s.

Eqke No. 177. April 3,1889 ; 4.27.21 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 90s.

Direction. *SE-NW*.

Max. H.M. 1.5mm (period = 0.7s).

Max. V.M. 0.2mm (period = 0.3s).

Character. Quick.

Remark. The preliminary tremor lasted for 3s, when the maximum horizontal motion suddenly took place, the movements being active for the next 20s. The maximum of the vertical motion, which was already well pronounced at the commencement, took place at the 2nd second, the motion being active for the next 10s. The duration of the vertical component was about 32s.

Hongo.

Horizontal motion. Duration = 80s. The motion, which was greater in the *EW* than in the *NS* direction, consisted at first of small quick vibrations. Towards the end the movements became regular and slow.

Max. 2a = 0.3 mm, $T_0 = 0.26$s ; $V = 3.6$ mm/s, $A = 87.5$ mm/s.²

In the *EW* component, the average period of the earlier quick vibrations was 0.19s (deduced from 70 vibrations), while that of the slow undulations in the end portion was 1.6s (deduced from 6 vibrations). In the *NS* component, the superposed ripples were insignificant, the average period of the slow movements, deduced from 34 vibrations, being 0.79s.

Vertical motion. Duration $=40$s. The motion was maximum at the commencement.

Max. $2a=0.06$ mm, $T_0=0.32$s ; $V=$small, $A=$small.

The average period was at first 0.27s (deduced from 13 vibrations), but towards the end 0.55s (deduced from 10 vibrations).

Eqke No. 178. April 3,1889 ; 4.40.51 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 179. April 6,1889 ; 7.40.13 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	50s.
Direction.	*SW-NE.*
Max. H.M.	0.3mm (period $=0.5$s).
Max. V.M.	Very small.
Character.	Quick.

Hongo.

Horizontal motion. Duration $=25$s.

Max. $2a=0.26$ mm, $T_0=0.49$s ; $V=1.7$ mm/s, $A=21.4$ mm/s².

The average period, deduced from 4 vibrations in the *NS* component, was 0.6s.

Vertical motion. Duration $=20$s. The motion was very small. The average period, deduced from 11 vibrations, was about 0.23s.

Eqke No. 180. April 8,1889 ; 0.48.0 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 181. April 14,1889 ; 5.22.54 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 182. April 18,1889 ; 2.7.41 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	——
Direction.	*ESE-WNW.*

Max. H.M. 0.8mm (period = 1s).

Max. V.M. 0.2mm (period = 0.7s).

Character. Gentle.

Area of disturbance. The earthquake, which originated under the sea between Izu and Ōshima, had a radius of propagation of about 120 *ri*. The land area of disturbance was 3050 sq. *ri* and included the following 16 provinces :—Izu, Suruga, Sagami, Awa, Kazusa, Shimosa, Musashi, Kai, Totomi, Mikawa, Owari, Hitachi, Shimotsuke, Kotsuke, Shinano, Mino. The area of *strong* motion was 160 sq. *ri* and included the provinces of Izu, Suruga (south-eastern portion), Sagami (south-western portion), and Awa (south-western part). Within an area of about 20 or 30 sq. *ri*, in the southern part of Izu, the earthquake was especially severe ; the motion, which lasted for about 3m, being in the *EW* direction. Thus, liquids were thrown out towards *E* and *W*, while some suspended articles swayed also in the same direction. At the town of Shimoda (province of Izu), an old *dozo* style tile-roofed house was shaken so strongly, that about 10 × 8 feet of its wall was thrown down. The area of *weak* motion was 960 sq. *ri* and included the provinces of Sagami (north-eastern part), Suruga, Totomi, Kai (southern part), Musashi (southern portion), Shimosa (south-western portion), Kazusa, Awa. Within this latter area the earthquake was felt distinctly. Finally, the area of *slight* motion, within which the motion was just sensible, was 1930 sq. *ri* and included the provinces of Shimosa (north-eastern part), Hitachi (southern part), Musashi (northern part), Shimotsuke (southern portion), Kotsuke (southern part), Kai (northern portion), Shinano (southern part), Mikawa, Owari, Mino (eastern portion). It is to be remarked that, in the Island of Ōshima, the shock was felt only weakly.

Hongo.

Horizontal motion. Duration = 9m. The earthquake whose motion was nearly equal in the two horizontal components, began very gently with extremely small slow movements, which lasted for 100s and whose average period was as follows :—

EW component......0.48s (deduced from 31 vibrations),

NS „ ......1.15s („ „ 29 „).

After the preliminary tremor, the movements became very large and slow, the maximum being the following:—

Max. $2a=17$ mm, $T_0=2.8s$; $V=19.0$ mm/s, $A=42.7$ mm/s.²

Other waves had still longer periods. The average period, deduced from 11 undulations in the end part of the *EW* component, was 6.5s.

Vertical motion. Duration = 6m. The motion consisted of extremely small slow undulations. The preliminary tremor lasted for about 100s, when the following maximum took place:—

Max. $2a=1.5$ mm, $T_0=0.31s$; $V=15.2$ mm/s, $A=308$ mm/s.²

The maximum was single and well defined, all the rest being small and irregular.

Eqke No. 183. April 18,1889; 2.54.11 p.m.

A tremor observed at the *Cent. Met. Observatory.*

The earthquake was also felt at the Miura District, province of Sagami.

Eqke No. 184. April 18,1889; 3.39.8 p.m.

Observation at the *Cent. Met. Observatory*:—

Direction. *SE-NW.*

Max. H.M. 0.3mm(period = 0.9s).

Character. Gentle.

Area of disturbance. The land area of disturbance was 1410 sq. *ri* and extended over the following 11 provinces:—Izu, Shimosa, Sagami, Musashi, Kazusa, Awa, Suruga(eastern part), Kai (eastern part), Kotsuke (south-eastern portion), Shimotsuke (southern portion), Hitachi (southern portion). The intensity was *weak* or *slight*, the motion being generally slow and horizontal. In Ōshima, the shock was felt very slightly.

Hongo.

Horizontal motion. Duration = 60s. The motion, which occurred

equally in the two horizontal directions, consisted of small gentle vibrations.

Max. 2a = 0.1 mm.

The average period was as follows :—

EW component, ... 0.48s (deduced from 21 vibrations),

NS „ . . . . . . 0.68s („ „ 21 „).

Vertical motion. Duration = 25s.

Max.2a = 0.05 mm, $T_0 = 0.39$s ; $V = 0.4$ mm/s, $A = 6.5$ mm/s.²

The average period deduced from 23 vibrations was 0.45s.

Eqke No. 185. April 18,1889 ; 4.0.1 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 186. April 19,1889 ; 0.18.46 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 187. April 19,1889 ; 2.29.19 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 188. April 19,1889 ; 3.0.27 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 50s.

Direction. *SW–NE.*

Max.H.M. 0.2 mm (period 0.6s).

Character. Gentle.

Eqke No. 189. April 19,1889 ; 5.50.39 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 90s.

Direction. *E–W.*

Max.H.M. 0.2mm (period = 0.6s).

Max.V.M. Very small.

Character. Gentle.

Eqke No. 190. April 19,1889 ; 10.53.55 p.m.

Observed as a tremor at the *Cent. Met. Observatory.*

Hongo.

Duration = 50s. This was a very small earthquake whose motion consisted of gentle vibrations, chiefly in the *NS* direction.

Max.2a = 0.2 mm, $T_0 = 1.1$s ; $V = 0.6$ mm/s, $A = 3.3$ mm/s.[2]

The average period, deduced from 13 vibrations in the *NS* component, was 1.0s.

Eqke No. 191. April 20,1889 ; 4.50.33 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 192. April 28,1889 ; 3.7.43 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	30s.
Direction.	*E-W.*
Max. H.M.	Small.
Max. V.M.	Very small.
Character.	Gentle.

Hongo.

Duration = 60s.

Max. 2a = 0.2mm, $T_c = 0.67$s ; $V = 0.9$ mm/s, $A = 8.8$ mm/s.[2]

Eqke No. 193. April 29,1889 ; 1.56.28 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration.	20s.
Direction.	*E-W.*
Max. H.M.	Small.
Max. V.M.	Very small.

Eqke No. 194. May 6,1889 ; 11.41.41 p.m.

Observation at fhe *Cent. Met. Observatory* :—

Duration.	60s.
Direction.	*NEN-SWS.*

Max. H.M. 0.4 mm (period = 0.5s).

Max. V.M. Very small.

Character. Sharp.

Hongo.

Horizontal motion. Duration = 120s. The max. 2a (= 0.4 mm) occurred at the commencement, the subsequent motion consisting of extremely small ripples superposed on slow undulations.

The period of the ripples, which existed chiefly in the *EW* direction, was 0.21s (deduced from 29 vibrations). The average period of the slow undulations was as follows :—

EW component....1.3s (deduced from 11 vibrations),

NS „ ....1.1s („ „ 38 „).

Vertical motion. The motion was very small.

Eqke No. 195. May 8,1889 ; 5.5.34 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 30s.

Direction. *N–S.*

Max. H.M. Small.

Max. V.M. Very small.

Character. Gentle.

Eqke No. 196. May 8,1889 ; 0.24.7 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 197. May 12,1889 ; 10.42.11 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 120s.

Direction. *SES–NWN.*

Max. H.M. 0.6mm (period = 2.0s).

Character. Gentle.

Area of disturbance. The earthquake was the greatest which happened since the winter of 1884, and which originated in central Japan, the

disturbance extending over the whole tract between Shimotsuke and Musashi on the north-east, and Bitchu, Awa and Sanuki on the west. The total land area of disturbance was 4800 sq. *ri* and included the following 37 provinces:—Mino, Owari, Ise, Mikawa, Totomi, Ōmi, Iga, Yamashiro, Wakasa, Echizen, Hida, Suruga, Kai, Izu, Sagami, Musashi, Shimosa (northern portion), Shimotsuke south-western portion), Kotsuke (southern portion), Shinano (southern part), Etchiu (southern part), Shima, Kii, Yamato, Izumi, Kawachi, Settsu, Tanba, Tango, Awaji, Tajima (eastern portion), Harima (eastern part), Bizen, Bitchu (eastern portion), Sanuki (eastern part), Awa (eastern part). The area of *strong* motion was 1500 sq. *ri* and included the following provinces:— Mino (southern part), Owari, Mikawa, Totomi, Suruga (western portion), Shinano (south-western portion), Ise (northern part), Iga (northern part), Ōmi, Yamashiro (eastern part), Tanba (eastern portion), Wakasa (eastern part), Echizen (southern part), Hida (southern portion); the shock being especially severe in the area of 220 sq. *ri*, which included Mino (southern part), Owari (northern part). The area of *weak* motion, within which the shock was distinctly felt, was 1630 sq. *ri* and extended over Echizen (northern portion), Kaga (southern part), Hida (central part), Shinano (central portion), Suruga (central part), Kai (western part), Shima, Ise (southern portion), Iga (southern portion), Kii (eastern portion), Yamato, Kawachi, Izumi (eastern part), Yamashiro (western portion), Settsu (eastern part), Tanba (central part), Wakasa (western portion), Tango (eastern portion). Finally the area of *slight* motion, within which the shock was just sufficiently intense to be felt, was 1670 sq. *ri* and extended over Kaga (northern part), Etchiu (southern part, Hida (northern portion), Shinano (northern part), Kotsuke (southern portion), Shimotsuke (south-western portion), Shimosa (northern portion), Musashi, Sagami, Izu, Suruga (eastern portion), Kai (eastern portion), Kii (western part), Izumi (western part), Awaji, Settsu (western portion), Tanba (western portion), Tango (western part), Tajima (eastern portion), Harima (eastern part), Bizen, Bitchu (eastern portion), Sanuki (eastern part), Awa (eastern part). In the meisoseismal area the motion was so violent that some damage was

produced. Thus in the vicinity of Gifu, the Nagara-gawa embankment was cracked for some length at a locality called Jōmon; bottles and earthen wares were thrown down from shelves; pendulum clocks stopped, etc., According to the observation at Gifu Meteorological Observatory, the duration of the earthquake was 2m 30s; the preliminary tremor lasted for 3s, when the motion became strong; at the 5th second, the *NS* component indicated a movement of about 15mm; immediatety thereafter strong *EW* component motion also set in and threw the *steady masses* of the seismograph out of their position, so that the subsequent movements could not be measured. The earthquake was much stronger than that of July 7, 1888. The damage produced in some of the Districts of the province of Mino was as follows:—(*Haguri District*) waters in puddy fields were rendered turbid in consequence of the shakings; (*Anpachi District*) liquids were thrown out, suspended lamps oscillated considerably, and pendulum clocks facing *S* or *N* were stopped; (*Motosu District*) some vessels were overturned; (*Mugi District*) walls of houses, whose foundation was not solid, were cracked, and liquids were thrown out; (*Kani District*) some pendulum clocks facing *N* stopped; Kamo District) some pendulum clocks stopped. In Aichi District, in the province of Owari, pendulum clocks facing *N* or *S* were stopped.

Hongo.

Duration = 120s. The earthquake, which began very gently, consisted of regular slow vibrations; there being no vertical motion.

Max. $2a = 0.5$ mm, $T_0 = 1.16$s; $V = 1.6$ mm/s, $A = 8.2$ mm/s.²

The average period of vibration was as follows:—

EW component......1.24s (deduced from 10 vibrations).
NS „ ......1.14s („ „ 53 „).

In earthquakes of this character, the amplitude remains, with some alternations of maximum and minimum groups, nearly constant for a considerable length of time and does not decrease so rapidly as in those earthquakes, whose motion is irregular and is superposed with ripples or entirely made up of these latter.

Eqke No. 198. May 17, 1889: 6.39.15 a.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 199. May 17, 1889 ; 8.34.25 a.m.
A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 200. May 17, 1889 ; 9.20.35 a.m.
A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 201. May 17, 1889 ; 9.39.37 a.m.
A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 202. May 17, 1889 ; 1.46.32 p.m.
Observation at the *Cent. Met. Observatory* :—
Duration. 30s.
Max. H.M. Small.

Hongo.
The motion was very small.

Eqke No. 203. May 20, 1889 ; 0.23.30 p.m.
A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 204. May 27, 1889 ; 6.22.56 p.m.
Observation at the *Cent. Met. Observatory* :—
Duration. 120s.
Direction. *E-W.*
Max. H.M. Very small.

Eqke No. 205. May 28, 1889 ; 5.26.22 a.m.
Observation at the *Cent. Met. Observatory* :—
Duration. 15s.
Direction. *E-W.*
Max. H.M. Small.

Eqke No. 206. May 28, 1889 ; 7.4.55 a.m.

Hongo.

The motion was very small.

Eqke No. 207. May 30, 1889; 10.27.22 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 120s.

Direction. *SE-NW.*

Max. H.M. 0.4mm (period = 0.8s).

Character. Quick.

Hongo.

Horizontal motion. Duration = 180s. The preliminary tremor, which consisted of very small and gentle movements, lasted for 60s, when 3 large vibrations suddenly took place. The subsequent motion was small and regular.

Max. 2a = 0.56mm, $T_o = 1.12s$; $V = 1.6$ mm/s, $A = 8.8$ mm/s.²

The average period, deduced from 20 vibrations in the *NS* component, was 1.13s. The motion was much larger in the *NS* than in the *EW* direction.

Vertical motion. Duration = 90s.

Max. 2a = 0.06 mm, $T_o = 0.32s$; $V = 0.6$ mm/s, $A = 11.6$ mm/s.²

Eqke No. 208. June 1, 1889; 6.15.21 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 25s.

Direction. *E-W.*

Max. H.M. 0.2 mm (period = 0.5s).

Character. Gentle.

Hongo.

Duration = 50s. This was a very small earthquake, whose motion was nearly equal in the two horizontal directions.

Eqke No. 209. June 3, 1889; 1.51.30 p.m.

Observed as a tremor at the *Cent. Met. Observatory.*

Hongo.

The motion was very small.

Eqke No. 210. June 3, 1889 ; 2 p.m.

Hongo.

The motion was very small.

Eqke No. 211. June 14, 1889 ; 0.26.41 p.m.

Observed as a tremor at the *Cent. Met. Observatory.*

Eqke No. 212. June 15, 1889 ; 10.10.2 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 50s.

Max. H.M. Small.

Character. Gentle.

Hongo.

Duration = 30s. This was a small earthquake, whose motion was nearly equal in the two horizontal directions and consisted of regular slow vibrations; there being no vertical component. The maximum occurred at the commencement.

Max.$2a = 0.14$ mm, $T_0 = 0.84$s ; $V = 0.5$ mm/s, $A = 3.9$ mm/s.²

The average period, deduced from 17 vibrations in the *NS* component, was 0.88s

Eqke No. 213. June 16, 1889 ; 2.31.24 p.m.

Observation at the *Cent Met. Observatory* :—

Duration. 30s.

Direction. *SE–NW.*

Max. H.M. Small.

Character. Quick.

Hongo.

Horizontal motion. Duration = 15s.

Max $2a = 0.1$mm.

The earlier portion of the EW component consisted of ripples, whose average period was about 0.21s.

Vertical motion. Small traces of vertical motion occurred only for a few seconds.

Eqke No. 214. June 20,1889 : 9.51.10 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 90s.

Direction. *SE-NW.*

Max H.M. 0.5mm (period=0.6s).

Max V.M. Small.

Character. Quick.

Hongo.

Horizontal motion. Duration=90s. In each horizontal component, the motion, which consisted at first of very small ripples, became gradually regular.

Max. 2a=0.1 mm, $T_0=0.56$ s ; $V=0.6$ mm/s, $A=6.3$ mm/s.²

The average period of the ripples was as follows :—

EW component......0.20s(deduced from 19 vibrations),

NS „ ......0.20s(„ „ 18 „).

The average period of the regular waves in the end portion was 0.55s (deduced from 51 vibrations in the *EW* component).

Vertical motion. Duration=70s. The motion, which was maximum at the commencement, consisted of a series of small quick vibrations decreasing gradually.

Max.2a=0.06mm, $T_0=0.19$s ; $V=1.0$ mm/s, $A=33$ mm/s².

Towards the end, the vibrations became slow ; the average period deduced from 32 vibrations being 0.57s.

Eqke No. 215. June 27,1889 ; 7.9.17 a.m.

Observation at the *Cent. Met. Observatory*:—

Duration. 60s.

Direction. *E-W.*

Max. H.M. 0.5mm (period = 2.5s).

Character. Gentle.

Hongo.

Duration = 90s. The motion, which occurred equally in the two horizontal components consisted of small slow vibrations and gradually attained the maximum, thence again very gradully diminishing There was no vertical motion.

Max. 2a = 0.2 mm, $T_0 = 1.14$s ; $V = 0.6$ mm/s, $A = 3.2$ mm/s.²

The average period of vibration was as follows : —

EW component......1.44s (deduced from 8 vibrations),

NS „ .....1.19s („ „ 36 „).

Eqke No. 216. July 3,1889 ; 5.39.58 p.m.

Observation at the *Cent. Met. Observatory* : —

Duration. 40s.

Direction. *E-W.*

Max. H.M. 0.3mm(period = 0.5s).

Max. V.M. Very small.

Character. Quick.

Hongo.

Duration = 30s. The motion, which was almost entirely in the *EW* direction, began with the maximum vibration, the subsequent portion consisting of extremely small movements. Towards the end, the motion became regular. There was no vertical motion.

Max. 2a = 0.24mm.

In the *EW* component, the average period of the earlier ripples, deduced from 19 vibrations, was 0.20s, while that deduced from 13 vibrations in the end portion was 0.43s.

Eqke No. 217. July 5,1889 ; 6.22.31 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 218. July 5,1889 ; 8.57.9 p.m.

A tremor observed at the *Cent. Met. Observatory.*

Eqke No. 219. July 18,1889; 10.33.18 p.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 35s.

Direction. *N-S.*

Max. H.M. Small.

Character. Sharp.

Hongo.

Duration=30s. The motion consisted of small quick vibrations. The vertical motion was very small.

Max.2a=0.1 mm, $T_0=0.20$s; $V=1.6$ mm/s, $A=49.3$ mm/s.²

The average period of vibration was as follows :—

EW component......0.19s (deduced from 27 vibrations),

NS " ......0.17s (" " 38 ").

The average period, deduced from 14 vibrations. In the end portion of the *EW* component, was 0.28s.

Eqke No. 220. July 30,1889; 2.3.40 a.m.

Observation at the *Cent. Met. Observatory* :—

Duration. 10s.

Direction. *E-W.*

Max. H.M. Small.

Character. Gentle.

Hongo.

Duration=15s. This was a very small earthquake of the same character as the preceding. The vertical motion was extremely small.

Max. 2a=0.1mm, $T_0=0.25$s; $V=1.3$ mm/s, $A=31.6$ mm/s.²

The average period was in the earlier part 0.17s (deduced from 10 vibrations), and towards the end 0.44s (deduced from 6 vibrations).

印刷所　三秀舍活版所
東京市神田區美土代町二丁目一番地
印刷者　島連太郎
東京市神田區美土代町二丁目一番地
震災豫防調査會
明治三十五年六月十三日發行
明治三十五年六月十二日印刷

[illegible]六[illegible]十[illegible]月[illegible]版

[illegible]十[illegible]六[illegible]

[illegible]

[illegible]

PUBLICATIONS

OF THE

Earthquake Investigation Committee

IN

FOREIGN LANGUAGES.

NO. 11.

TOKYO. 1902.

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TŌKYŌ, 1902.

PRINTED BY THE TOKYO PRINTING COMPANY, LIMITED.

MACRO-SEISMIC MEASUREMENT IN TOKYO.

II and III.

BY

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Member of the Imperial Earthquake Investigation Committee.

CONTENTS.

PREFACE.*

The following pages constitute the second and third reports on the Tokyo Macro-seismic Measurement. Part II is a discussion of the results of the Observations between Sept. 1887 and July 1889, given in the *Publications*, No. 10; while Part III contains some miscellaneous notes on the seismographical observations between 1884 and 1898.

The abbreviations used in the description of the seismograms are as follows :—

H. M.	Horizontal motion.
V. M.	Vertical motion.
2a.................	Range of motion (double amplitude), *in mm.*
Max. 2a	Maximum range of motion, *in mm.*
T	Period (complete) of vibration, *in second.*
T_0.................	Period (complete) of vibration corresponding to max. 2a, *in second.*

$$V = \frac{2\pi a}{T_0} = \text{Maximum velocity.}$$

$$A = \frac{4\pi^2 a}{T_0^2} = \text{Maximum acceleration.}$$

* The reader is also referred to the *Publications*, No. 10, pp. i-v.

Macro-seismic Measurement in Tokyo. II.

Summary of the Results of the Observations in Tokyo, between Sept. 1887 and July 1889.

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1. List of the Earthquakes.

Table I gives the dates and times of occurrence of the 220 earthquakes observed, with the exception of the first nine, between Sept. 1887 and July 1889 at the following three stations in Tokyo :—

Hongo (Seismological Institute),
Hitotsubashi,
Central Meteorological Observatory.

The Seismological Institute is situated on the higher part of Tokyo, where the ground is hard and consists of loam. On the other hand, the ground at Hitotsubashi, which was marshy till recent times, is soft, water being already met with at a depth of 2 or 3 feet. These two places are, therefore, to be regarded respectively as examples of a solid natural ground and a very shaky soil. Again the old castle ground, on which the Central Meteorological Observatory is situated, is surrounded by solid high masonry walls, rising about 22 metres above the waters of the moats with which the latter are encircled. As the site of the castle was originally marshy, we have here a case of highly solid made-ground.

Of the 220 earthquakes, numbered in order of date and divided into seven groups I to VII according to the position of the origins (see § 2), 6 were felt *strongly* in Tokyo, while 69 were mere tremors or very slight shakings whose range of motion was too small to be accurately measured from the seismograms. The number of the earthquakes observed only in Tokyo was 96, these being for the most part small local shocks. On the other hand, 19 earthquakes were very extensive, the mean radii of propagation being in each case greater than 200 km.

TABLE I.—LIST OF EARTHQUAKES OBSERVED IN TOKYO.

Sept. 1887 –July 1889.*

No.	Group.	Date.	Time of occurrence.	No.	Group.	Date.	Time of occurrence.
1	VII	Sept. 26th, 1885	0. 30. 0 pm.	31	I	Dec. 17th, 1887	11. 41. 14 pm.
2	V	July 2nd, 1886	0. 33. 6 pm.	32	I	„ 19th, 1887	6. 0. 12 pm.
3	III	Dec. 26th, 1886	5. 48. 5 pm.	33	I	„ 21st, 1887	2. 5. 55 pm.
4	V	June 20th, 1887	8. 38. 30 am.	34	VI	„ 24th, 1887	4. 9. 41 am.
5	III	„ 22nd, 1887	7. 42. 39 am.	35	I	„ „ 1887	7. 51. 38 am.
6	?	„ 30th, 1887	8. 0. 35 am.	36	I	„ 27th, 1887	
7	IV	July 2nd, 1887	3. 16. 24 pm.	37	II	„ 31st, 1887	1. 24. 45 am.
8	?	„ 11th, 1887	3. 7. 42 pm.	38	II	Jan. 1st, 1888	3. 31. 38 pm.
9	VI	„ 22nd, 1887	8. 27. 0 pm.	39	V	„ 11th, 1888	8. 50. 36 am.
10	IV	Sept. 2nd, 1887	5. 52. 49 pm.	40	I	„ 13th, 1888	
11	IV	„ 3rd, 1887	4. 50. 30 am.	41	I	„ 14th, 1888	5. 31. 55 pm.
12	I	„ 4th, 1887		42	V	„ 27th, 1888	10. 5. 33 am.
13	V	„ 5th, 1887	3. 23. 23 pm.	43	V	Feb. 2nd, 1888	1. 15. 15 pm.
14	III	„ 6th, 1887		44	V	„ „ 1888	2. 23. 46 pm.
15	V	„ 8th, 1887	3. 55. 0 pm.	45	V	„ „ 1888	3. 0. 14 pm.
16	I	„ 11th, 1887	9. 20. 0 am.	46	V	„ 2nd, 1888	3. 41. 27 pm.
17	III	„ 13th, 1887	8. 16. 52 pm.	47	I	„ 3rd, 1888	2. 31. 56 pm.
18	IV	„ 15th, 1887	4. 41. 41 pm.	48	VI	„ 5th, 1888	0. 50. 56 pm.
19	V	„ 25th, 1887	8. 56. 11 am.	49	III	„ 10th, 1888	3. 26. 55 pm.
20	II	Nov. 15th, 1887	3. 54. 51 pm.	50	II	„ „ 1888	6. 38. 7 pm.
21	IV	„ 20th, 1887	0. 3. 45 pm.	51	I	„ 11th, 1888	3. 38. 56 pm.
22	I	„ 23rd, 1887	6. 5. 0 pm.	52	I	„ 13th, 1888	11. 33. 44 am.
23	V	„ 30th, 1887	9. 24. 18 am.	53	II	„ 15th, 1888	3. 43. 38 pm.
24	I	Dec. 5th, 1887	0. 57. 16 pm.	54	V	„ 17th, 1888	0. 16. 17 pm.
25	I	„ 8th, 1887	8. 3. 0 pm.	55	V	„ 18th, 1888	6. 13. 45 pm.
26	I	„ 11th, 1887	9. 55. 47 pm.	56	VI	„ 22nd, 1888	10. 24. 28 am.
27	I	„ 14th, 1887	10. 55. 9 pm.	57	I	„ „ 1888	11. 10. 50 pm.
28	II	„ 16th, 1887	8. 28. 21 am.	58	I	„ 24th, 1888	2. 7. 6 am.
29	II	„ 17th, 1887	0. 17. 8 am.	59	II	March 1st, 1888	3. 30. 15 pm.
30	II	„ „ 1887	6. 17. 22 am.	60	II	„ „ 1888	9. 54. 12 pm.

* The times are given in the First Standard Japan Time, or that of Long. 135° E.

No.	Group.	Date.	Time of occurrence.	No.	Group.	Date.	Time of occurrence.
61	II	March 9th, 1888	4. 54. 16 am.	96	I	July 14th, 1888	7. 31. 59 am.
62	IV	„ 16th, 1888	6. 43. 0 am.	97	V	„ „ 1888	4. 42. 44 pm.
63	I	„ 17th, 1888	7. 55. 36 pm.	98	I	„ 22nd, 1888	2. 27. 48 am.
64	I	April 1st, 1888	6. 17. 08 am.	99	I	„ 24th, 1888	7. 57. 43 am.
65	II	„ 5th, 1888	2. 30. 29 pm.	100	I	„ 29th, 1888	9. 48. 21 pm.
66	I	„ 8th, 1888	2. 22. 32 pm.	101	I	Aug. 1st, 1888	9. 25. 18 pm.
67	I	„ 7th, 1888		102	V	„ 11th, 1888	9. 31. 42 am.
68	I	„ 16th, 1888	11. 6. 43 pm.	103	VI	„ 12th, 1888	11. 42. 27 am.
69	II	„ 27th, 1888	8. 34. 34 am.	104	V	„ 17th, 1888	3. 49. 50 am.
70	III	„ 29th, 1888	10. 0. 33 am.	105	I	„ 18th, 1888	1. 22. 0 am.
71	V	„ 30th, 1888	5. 44. 38 am.	106	I	„ 19th, 1888	9. 19. 26 am.
72	I	May 5th, 1888	8. 52. 24 pm.	107	I	„ „ 1888	11. 47. 25 am.
73	I	„ 8th, 1888	4. 7. 56 am.	108	I	Sept. 2nd, 1888	5. 45. 0 am.
74	I	„ „ 1888	4. 51. 41 am.	109	I	„ 4th, 1888	5. 10. 0 am.
75	II	„ 10th, 1888	10. 12. 00 am.	110	I	„ „ 1888	1. 36. 11 pm.
76	II	„ 13th, 1888	4. 51. 52 am.	111	I	„ 5th, 1888	0. 6. 35 am.
77	V	„ „ 1888	11. 17. 41 am.	112	I	„ 6th, 1888	4. 9. 25 am.
78	II	„ 22nd, 1888	6. 9. 20 pm.	113	IV	„ 10th, 1888	9. 22. 0 am.
79	IV	„ 24th, 1888	9. 35. 37 am.	114	IV	„ 11th, 1888	8. 34. 54 am.
80	V	„ „ 1888	11. 45. 5 am.	115	III	„ 18th, 1888	2. 45. 39 am.
81	IV	„ 26th, 1888	6. 17. 14 pm.	116	I	„ 24th, 1888	5. 21. 30 am.
82	IV	„ 27th, 1888	7. 5. 9 pm.	117	V	„ „ 1888	5. 37. 13 pm.
83	II	June 3rd, 1888	7. 53. 8 am.	118	III	„ 28th, 1888	7. 5. 21 am.
84	IV	„ 12th, 1888	9. 6. 27 pm.	119	III	Oct. 9th, 1888	1. 7. 55 am.
85	I	„ 15th, 1888	0. 21. 25 am.	120	I	„ 10th, 1888	4. 20. 24 pm.
86	IV	„ 18th, 1888	2. 20. 31 pm.	121	III	„ 12th, 1888	7. 40. 56 am.
87	I	„ „ 1888	3. 17. 6 pm.	122	V	„ 20th, 1888	6. 15. 16 am.
88	I	„ „ 1888	9. 57. 14 pm.	123	II	Nov. 2nd, 1888	1. 48. 1 pm.
89	IV	„ 19th, 1888	6. 29. 57 am.	124	III	„ 3rd, 1888	0. 51. 14 am.
90	I	„ 22nd, 1888	7. 6. 25 am.	125	III	„ „ 1888	8. 13. 33 am.
91	I	„ 24th, 1888	11. 8. 20 pm.	126	IV	„ 5th, 1888	4. 22. 55 am.
92	IV	July 2nd, 1888	4. 51. 56 am.	127	I	„ 6th, 1888	4. 38. 37 pm.
93	I	„ 7th, 1888	9. 37. 37 am.	128	I	„ 7th, 1888	10. 27. 34 pm.
94	VII	„ „ 1888	5. 25. 43 pm.	129	I	„ 10th, 1888	1. 37. 44 pm.
95	I	„ 11th, 1888	3. 38. 35 pm.	130	I	„ 16th, 1888	0. 42. 49 am.

No.	Group.	Date.	Time of occurrence.	No.	Group.	Date.	Time of occurrence.
131	V	Nov. 20th, 1888	0. 53. 29 am.	166	I	March 3rd, 1889	4. 35. 19 pm.
132	I	„ 22nd, 1888	1. 27. 43 pm.	167	I	„ 4th, 1889	7. 24. 25 am.
133	I	„ 23rd, 1888	5. 13. 30 pm.	168	I	„ 18th, 1889	6. 41. 12 am.
134	VI	„ 24th, 1888	2. 3. 23 am.	169	IV	„ 21st, 1889	6. 9. 23 pm.
135	I	„ 25th, 1888	4. 50. 15 pm.	170	I	„ 26th, 1889	2. 41. 48 pm.
136	I	Dec. 1st, 1888		171	IV	„ 28th, 1889	1. 20. 10 am.
137	IV	„ 3rd, 1888	0. 24. 47 pm.	172	V	„ „ 1889	10. 22. 55 am.
138	VI	„ 6th, 1888	7. 27. 42 am.	173	V	„ „ 1889	7. 18. 23 pm.
139	I	„ 16th, 1888	4. 19. 3 am.	174	V	„ 31st, 1889	6. 42. 15 am.
140	I	„ 21st, 1888		175	I	„ „ 1889	8. 13. 3 am.
141	I	„ 28th, 1888	3. 28. 4 am.	176	V	„ 31st, 1889	5. 59. 42 pm.
142	III	Jan. 1st, 1889	3. 4. 50 pm.	177	IV	April 3rd, 1889	4. 27. 21 pm.
143	II	„ 1st, 1889	7. 5. 30 pm.	178	IV	„ „ 1889	4. 40. 51 pm.
144	V	„ 3rd, 1889	7. 58. 6 am.	179	II	„ 6th, 1889	7. 40. 13 pm.
145	I	„ 5th, 1889		180	II	„ 8th, 1889	0. 48. 0 pm.
146	I	„ 7th, 1889		181	II	„ 14th, 1889	5. 22. 54 am.
147	V	„ 12th, 1889	8. 34. 3 pm.	182	IV	„ 18th, 1889	2. 7. 41 pm.
148	I	„ 13th, 1889		183	I	„ „ 1889	2. 54. 11 pm.
149	I	„ 27th, 1889	2. 28. 47 pm.	184	VII	„ „ 1889	3. 39. 8 pm.
150	I	„ 29th, 1889		185	I	„ „ 1889	4. 0. 1 pm.
151	I	Feb. 5th, 1889	2. 27. 39 pm.	186	II	„ 19th, 1889	0. 18. 46 pm.
152	II	„ 9th, 1889	7. 41. 38 am.	187	I	„ „ 1889	2. 29. 19 am.
153	I	„ 15th, 1889	5. 14. 3 pm.	188	II	„ „ 1889	3. 0. 27 pm.
154	IV	„ 18th, 1889	6. 9. 32 am.	189	V	„ „ 1889	5. 50. 39 pm.
155	III	„ „ 1889	6. 27. 45 am.	190	I	„ „ 1889	10. 53. 55 pm.
156	III	„ 18th, 1889	7. 48. 52 am.	191	I	„ 20th, 1889	4 50. 33 pm.
157	I	„ „ 1889	8. 2. 0 am.	192	V	„ 28th, 1889	3. 7. 43 am.
158	III	„ „ 1889	10 10. 56 am.	193	I	„ 29th, 1889	1. 56. 28 am.
159	I	„ 19th, 1889	2. 57. 43 pm.	194	II	„ 6th, 1889	11. 41. 41 pm.
160	I	„ 20th, 1889	9. 19. 37 pm.	195	III	May 8th, 1889	5. 5. 34 am.
161	IV	„ 21st, 1889	5. 52. 21 am.	196	I	„ 8th, 1889	0. 24. 7 pm.
162	I	„ 21st, 1889	8. 19. 23 am.	197	VII	„ „ 1889	10. 42. 11 am.
163	IV	„ 21st, 1889	11. 1. 14 am.	198	I	„ 12th, 1889	6. 39. 15 am.
164	I	„ 21st, 1889	9. 27. 52 pm.	199	I	„ 17th, 1889	8. 34. 25 am.
165	I	„ 23rd, 1839	11. 27. 21 pm.	200	I	„ „ 1889	9. 20. 35 am.

No.	Group.	Date.	Time of occurrence.	No.	Group.	Date.	Time of occurrence.
201	I	May 17th, 1889	9. 39. 37 am.	211	II	June 14th, 1889	0. 26. 41 pm.
202	I	„ „ 1889	1. 46. 32 pm.	212	V	„ 15th, 1889	10. 10. 2 am.
203	V	„ 20th, 1889	0. 23. 30 pm.	213	I	„ 16th, 1889	2. 31. 24 pm.
204	I	„ 27th, 1889	6. 22. 56 pm.	214	V	„ 20th, 1889	9. 51. 10 pm.
205	I	„ 28th, 1889	5. 26. 22 am.	215	VII	„ 27th, 1889	7. 9. 17 am.
206	I	„ 28th, 1889	7. 4. 55 am.	216	II	July 3rd, 1889	5. 39. 58 pm.
207	V	„ 30th, 1889	10. 27. 22 pm.	217	I	„ „ 1889	6. 22. 31 pm.
208	II	June 1st, 1889	6. 15. 21 pm.	218	I	„ „ 1889	8. 57. 9 pm.
209	V	„ 3rd, 1889	1. 51. 30 pm.	219	II	„ 18th, 1889	10. 33. 18 pm.
210	V	„ „ 1889	2. 0. 0 pm.	220	IV	„ 30th, 1889	2. 3. 40 am.

2. Distribution of the Earthquake Origins.

Pl. I shows the geographical distribution of the origins of the earthquakes which were observed in Tokyo between Sept. 1887 and July 1889, each of the red points marking the position of a seismic epicentre ; except for Tokyo, where there were 96 local shocks, these being represented by a single sign (✕).

The majority of the epicentres are grouped into five zones II, III, IV, V and VI (shaded in the map) whose boundaries have been determined by drawing free-hand curves through the mean positions of the broken lines connecting the successive outer-most points of each group.* The axes or lines drawn through the middle of these zones may be regarded as marking the weak places in the Kwanto provinces and under the sea to the north-east of the Honshiu, along which earthquakes disturbing Tokyo most frequently originate.

Of the five zones, II coincides with a part of the Tone-*gawa* valley ; while III and IV extend, also in nearly the same direction, respectively from the south-eastern part of Shimosa to the north-western part of Musashi, and from the north of Kazusa to the centre of Kai. On the other hand the zone V is situated under the sea at a mean distance of about 55 km from the coast of Kazusa, Hitachi and Iwaki, to which it is parallel. VI is to be regarded as the northern continuation of V. Strong and large earthquakes most frequently originate from the zone V.

Pl. II shows the distribution of the origins of the earthquakes which happened between Sept. 1887 and July 1889 in Central Japan, but were not felt in Tokyo. The origins are grouped into six zones A, B, C, D, E and F. The last zone is really composed of two branches F_1 and F_2 joined normally to each other. C, D, and

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* The zone VI is not indicated in the map.

F, are identical respectively with the zones I, II and III in Pl. I, while A is nearly identical with the zone V.

From Pl. I and Pl. II it will be seen that the earthquake origins in the central and eastern portions of Honshiu are distributed in two systems of zones ; one nearly in the direction ESE—WNW and the other in the direction NEN—SWS. The former may be regarded as being radial and the latter concentric, or parallel, to the arc formed by the group of the Japanese Islands.

The division into seven groups, I to VII, of the 220 earthquakes given in Table I, which is in accordance with the geographical distribution of the origins as indicated in Pl. I, is as follows.—

Group	I.	Local earthquakes, recorded only in Tokyo.				
,,	II.	Earthquakes	which	originated	in zone	II.
,,	III.	,,	,,	,,	,,	III.
,,	IV.	,,	,,	,,	,,	IV.
,,	V.	,,	,,	,,	,,	V.
,,	VI.	,,	,,	,,	,,	VI.
,,	VII.	,,	of miscellaneous origins.			

3. Origins and Areas of Disturbance of the different earthquakes.

In Table II, I give the data relating to the position of the origins and the areas of disturbance of the different earthquakes, arranged in the following order.—

(1) Earthquake Number and Group.

(2) Intensity of motion at epicentre, or, in case of a submarine origin, that at the most strongly shaken district ; the intensity for non-destructive earthquakes being distinguished as *strong*, *weak* or *slight*.*

* See the *Publications*, No. 10, p. iii.

(3) Latitude and longitude of the earthquake centre inferred in each case from the isoseismal lines.

(4) Semi-major and semi-minor axes of the area of disturbance, which is generally more or less elliptical. In case of the area being nearly circular, the mean radius is given.*

(5) The direction of the major axis of the area of disturbance.

(6) Distance and direction of the earthquake origin from Tokyo.

(7) *Remark*, giving short notes on the area of disturbance.

The earthquakes not given in Table II are those recorded only in Tokyo.

* The *area* means here the area within which the seismic motion was sufficiently intense to be felt.

TABLE II.—ORIGINS AND AREAS OF

Earthquake.		Intensity.	Position of earthq. origin.		Area of disturbance.		Direction of the major axis.
No.	Group.		Lat. N.	Long. E.	Semi-major axis. (km)	Semi-minor axis. (km)	
10	IV	*Weak.*	35° 30′	140° 16′	85	41	E–W.
11	IV	*Slight.*	35 25	139 46	27	16	N 25° E–S 25° W.
13	V	*Violent.*	35 33	141 10	—	—	——
14	III	*Weak.*	35 45	140 20	68	33	N 20° E–S 20° W.
15	V	„	36 45	141 24	—	—	——
17	III	„	36 7	139 3	103	74	N 63° E–S 63° W.
18	IV	*Slight.*	35 33	140 9	43	36	N 60° W–S 60° E.
19	V	*Strong.*	35 55	141 7	—	—	——
20	II	*Weak.*	36 23	140 2	96	96	——
21	IV	„	35 28	139 52	100	84	N 65° W–S 65° E.
23	V	„	35 55	141 30	—	—	——
28	II	„	36 9	139 58	200	110	N 78° E–S 78° W.
29	II	*Slight.*	36 8	140 0	60	60	——
30	II	*Weak.*	36 16	140 13	92	92	——
34	IV	„	35 36	140 15	43	43	——

DISTURBANCE OF THE EARTHQUAKES.

Distance and direction of earthquake origin from Tokyo.			REMARK
49	km,	S 71° E	——
26	„	S	Observed only in Tokyo and at Kamakura.
125	„	S 85° E	This was an extensive earthquake, the northward and the westward radii of the land area being respectively 400 and 360 km. The *strong* motion area was a sector of 110° and of radius 154 km with the origin at the Inubozaki, while the *violent* motion area was a similar sector of radius 60 km.
52	„	N 77° E	——
190	„	N 52° E	A moderately extensive earthquake, the northward and the WSW' ward radii of the land area being respectively 200 and 190 km; Tokyo on the SW corner of the area.
80	„	N 50° W	——
37	„	S 74° E	——
125	„	N 77° E	A moderately extensive earthquake, the northward and the WSW' ward radii of the land area being respectively 230 and 140 km; Tokyo on the WSW edge. Motion felt *strongly* in a sector of 110° and of radius 49 km, with Inubozaki as centre.
85	„	N 20° E	The area was nearly circular.
22	„	S 30° E	——
160	„	N 78° E	The NNW and W radii of the land area were respectively 240 and 230 km.
60	„	S 21° W	——
55	„	N 23° E	The area was nearly circular.
78	„	N 29° E	„ „ „
43	„	S 72° E	„ „ „

TABLE II. (*Continued.*)

Earthquake.		Intensity.	Position of earthq. origin.		Area of disturbance.		Direction of the major axis.
No.	Group.		Lat. N.	Long. E.	Semi-major axis. (km)	Semi-minor axis. (km)	
37	II	*Slight.*	36° 5′	140° 10′	68	68	——
38	II	*Weak.*	36 22	139 55	93	58	N 24° E–S 24° W
39	V	,,	36 0	141 25	—	—	——
42	V	,,	35 15	140 38	82	32	N 50° W–S 50° E
43	V	*Strong.*	36 5	140 49	—	—	——
44	V	*Weak.*	36 10	141 12	150	120	N–S
45	V	*Slight.*	36	141	—	—	——
46	V	*Strong.*	36 6	141 8	—	—	——
48	VI	,,	41 30	143 0	—	—	——
49	III	*Weak.*	35 46	140 5	34	34	——
50	II	,,	35 58	140 19	84	84	——
53	II	*Slight.*	36 4	139 45	58	45	N 14° W–S 14° E
54	V	*Weak.*	35 16	140 43	93	30	N 65° W–S 65° E
55	V	*Slight.*	35 41	141 11	—	—	——
56	VI	*Strong.*	38 30	142 30	—	—	——

Distance and direction of earthquake origin from Tokyo.	REMARK.
68 km, N 40° E	The area was nearly circular.
80 „ N 13° E	——
150 „ N 75° E	The area was moderately extensive.
90 „ S 62° E	——
107 „ N 65° E	The land area of *strong* motion was nearly a semi-circle of radius 71 km and included Shimosa, southern part of Hitachi and eastern portion of Musashi, Tokyo being on the WSW edge. The N and WSW radii of the area of disturbance were respectively 290 and 220 km.
140 „ N 67° E	——
— —	——
130 „ N 69° E	The N and W radii of the area of disturbance were respectively 250 and 200 km. The area of *strong* motion was nearly a semi-circle of radius 43 km and included the SE part of Hitachi and NE portion of Shimosa. This earthquake was much similar to, but slightly smaller than, Eqke. No. 43.
600 „ N 27° E	This was a very extensive earthquake, which shook the whole NE Japan, from Hokkaido down to the boundary of Echigo and eastern portion of Kotsuke and of Musashi, the radius on SWS being 600 km. The motion was felt *strongly* in Hidaka, E portion of Iburi, E portion of Oshima, E half of Mutsu, Rikuchu, and NE portion of Rikuzen.
32 „ N 68° E	The area of disturbance was nearly circular.
60 „ N 54° E	„ „ „
44 „ N	——
95 „ S 65° E	——
130 „ E	The land area of disturbance was a circular sector of radius 80 km, whose angle was 120°.
390 „ N 38° E	This was a very extensive earthquake, which shook the whole of NE Japan, from the SE part of Hokkaido down to the boundary of Echigo and the eastern portions of Kotsuke and Musashi. The motion was felt strongly in the SE portion of Rikuchu, in Rikuzen and in the NE corner of Iwaki. The SWS radius of the area of disturbance was 390 km.

TABLE II. (*Continued.*)

Earthquake.		Intensity.	Position of earthq. origin.		Area of disturbance.		Direction of the major axis.
No.	Group.		Lat. N.	Long. E.	Semi-major axis. (km)	Semi-minor axis. (km)	
59	II	*Slight.*	36° 8′	139° 43′	65	65	——
60	II	*Weak.*	36 7	139 50	67	57	N 26° W–S 26° E
61	II	,,	36 25	139 58	93	93	——
62	IV	*Strong.*	35 21	139 10	115	115	——
65	II	,,	36 15	139 57	—	—	——
69	II	*Slight.*	36 0	140 7	60	60	——
70	III	*Strong.*	35 49	139 31	—	—	——
71	V	*Weak.*	36 25	141 0	130	67	N 50° E–S 50° W
75	II	*Slight.*	36 5	139 57	59	34	N–S
76	II	*Weak.*	35 57	140 5	69	49	N 10° W–S 10° E
77	V	,,	36 7	141 0	—	—	——
78	II	*Strong.*	36 4	140 5	—	—	——
79	IV	*Weak.*	35 33	139 8	75	34	E–W
80	V	,,	35 40	141 0	—	—	——
81	IV	,,	35 33	139 27	40	32	E–W

Distance and direction of earthquake origin from Tokyo.	REMARK.
53 km, N 3° W	The area of disturbance was nearly circular.
51 „ N 9° E	This was very similar to No. 59.
89 „ N 15° E	The area of disturbance was nearly circular.
63 „ S 57° W	The area of disturbance was nearly circular; the motion was felt *strongly* in the W portion of Sagami and E portion of Suruga.
69 „ N 15° E	This was an extensive earthquake, whose ENE and WSW radii of propagation were respectively 260 and 220 km. The area of *strong* motion was roughly a circle of radius 60 km and included the central and SW parts of Hitachi, S half of Shimotsuke, E corner of Kotsuke, NE half of Musashi, and NW half of Shimosa.
52 „ N 41° E	The area of disturbance was nearly circular.
29 „ N 50° W	This was an extensive earthquake, the NEN and WSW radii of propagation being respectively 340 and 270 km. The area of *strong* motion was an ellipse whose two semi axes were respectively 130 and 87 km and the direction of whose major axis was N 34° E-S 34° W.
140 „ N 52° E	——
48 „ N 15° E	——
44 „ N 40° E	——
120 „ N 66° E	The land area of disturbance was nearly a semi-circle of radius 82 km.
56 „ S 51° W	This was a large earthquake, the SW and NEN radii of propagation being respectively 180 and 350 km. The area of *strong* motion was an ellipse, whose two semi-axis were respectively 68 and 39 km, and whose major axis was in the direction N 48° E-S 48° W.
57 „ S 78° W	——
110 „ E	——
32 „ S 68° W	——

TABLE II. *(Continued.)*

Earthquake.		Intensity.	Position of earthq. origin.		Area of disturbance.		Direction of the major axis.
No.	Group.		Lat. N.	Long. E.	Semi-major axis. (km)	Semi-minor axis. (km)	
82	IV	*Strong.*	35° 42′	139° 4′	71	45	N 70° E–S 70° W
83	II	,,	36 0	140 14	128	128	——
84	IV	,,	35 33	139 6	100	74	——
86	IV	,,	35 33	139 17	104	76	N 33° E–S 33° W
89	IV	*Weak.*	35 30	139 14	29	19	N 27° E–S 27° W
92	IV	,,	35 36	139 11	60	46	E–W
94	VII	*Strong.*	35 27	136 40	—	—	——
97	V	*Weak.*	36 0	141 15	—	—	——
102	V	,,	35 38	140 53	90	90	——
103	VI	*Strong.*	37 38	141 30	—	—	——
104	V	,,	36 17	141 0	140	140	——
113	IV		35 34	138 36	140	56	E 6° N–W 6° S
114	IV		—	—	29	16	E 60° N–W 60° S
115	III		—	—	30	19	N 50° E–S 50° W
117	V		—	—	63	38	N 40° E–S 40° W

Distance and direction of earthquake origin from Tokyo.			REMARK.
63	km	S 85° W	Felt strongly in the E portion of Kai.
58	"	N 52° E	The land area of disturbance was nearly a semi-circle of radius 128 km with Mito for the centre. The motion was felt *strongly* in the NE part of Shimosa and S portion of Hitachi.
56	"	S 78° W	The motion was felt *strongly* in the E portion of Kai and N part of Sagami.
52	"	S 77° W	This earthquake was very similar to No. 84. The motion was felt strongly in the E portion of Kai and N part of Sagami.
21	"	S 10° W	This was a very small eathquake.
51	"	N 80° E	Tokyo was at the E end of the major axis.
280	"	W	This was an extensive earthquake, whose iso-seismals were similar to those of Mino-Owari eqke of Oct. 28th, 1891. The E, N and SW radii of propagation were respectively 220, 107 and 165 km; Tokyo being at the eastern end of the shaken area. The origin was in the NW part of Mino, and the area of *strong* motion was an irregular ellipse whose two semi-axes were respectively 74 and 34 km, the major axes being parallel to the direction N 56° W–S 56° E.
144	"	N 75° E	The land area of disturbance was 150 km in length and 90 km in breadth.
100	"	E	The area of disturbance was nearly circular, Tokyo being on the W boundary.
270	"	N 37° E	This was a large earthquake, whose disturbed land area was 410 km long and 120 km wide, and extended from the S parts of Rikuchu and Ugo to the NE part of Musashi. The area of *strong* motion included nearly the whole of Rikuzen and Iwaki and eastern portion of Iwashiro.
130	"	N 58° E	The N and W radii of propagation were respectively 210 and 190 km, Tokyo being on the WSW edge of the area. The motion was felt *strongly* at a central portion of the coast of Hitachi.
110	"	W	——
21	"	SW	——
23	"	E	——
	"	NE	——

TABLE II. (*Continued.*)

Earthquake.		Intensity.	Position of earthq. origin.		Area of disturbance.		Direction of the major axis.
No.	Group.		Lat. N.	Long. E.	Semi-major axis. (km)	Semi-minor axis. (km)	
118	III	—	—	—	72	36	N 70° W–S 70° E
119	III	*Slight.*	35° 42′	140° 5	34	19	——
121	III	*Weak.*	36 6	139 11	51	38	N 12° E–S 12° W
122	V	*Strong.*	36 20	141 9	190	180	——
123	II	,,	36 11	139 32	120	90	N 40° E–S 40° W
124	III	*Slight.*	35 48	140 0	32	16	N 48° E–S 48° W
125	III	*Strong.*	35 39	140 22	92	92	——
126	IV	*Weak.*	35 34	140 10	44	44	——
131	V	,,	36 30	141 30	—	—	——
134	VI	*Strong.*	38 20	143 0	—	—	——
137	IV	*Weak.*	35 25	140 5	41	23	N 70° W–S 70° E
138	VI	*Strong.*	38 30	142 13	—	—	——
142	III	*Weak.*	35 54	139 31	98	68	N 70° E–S 70° W
143	II	*Strong.*	36 0	139 51	—	—	——
144	V	*Weak.*	35 20	141 5	—	—	——

Distance and direction of earthquake origin from Tokyo.	RAMARK.
68 km, E	——
30 „ N 80° E	——
52 „ N 12° E	——
150 „ N 61° E	This was an earthquake of moderate extension, whose land area extended from the SE part of Rikuzen to the NE part of Sagami. The motion was felt *strongly* at Inubo-zaki and NE corner of Hitachi.
62 „ N 22° W	The shock was felt *strongly* in a limited area in the Saitama and Osato Districts of Musashi.
26 „ N 48° E	——
53 „ E	The earthquake was moderately extensive, the area being an irregular circle. The motion was felt *strongly* in a narrow elliptical area whose two axes were respectively 75 and 22 km and which extended, in direction N 22° W–S 22° E, from the N part of Kazusa to the middle portion of Shimosa.
38 „ S 75° E	The area of disturbance was nearly circular.
190 „ N 58° E	This was a large earthquake, whose land area was 270 km long and 80 km wide, Tokyo being on the SW edge.
430 „ N 45° E	This was a very large earthquake, whose land area was 1100 km long and 90 km wide, and extended from the middle of Hokkaido down to the eastern portion of Sagami. The motion was felt *strongly* along the coast of Rikuzen and N portion of Iwaki.
41 „ S 45° E	——
380 „ N 35° E	This was an extensive earthquake, whose N, WNW and SWS radii of propagation were respectively 190, 230 and 390 km, Tokyo being at the SWS extremity of the area. The motion was felt *strongly* along the coast, between Miyako and the mouth of the Abukuma-*gawa*, the width of the zone being 27 km.
29 „ N 18° W	——
38 „ N 8° E	This was an extensive earthquake, whose NEN, SW and WNW radii of propagation were respectively 260, 180 and 150 km. The motion was felt *strongly* in an elliptical area whose two axes were respectively 155 and 106 km and whose major axis was in the direction N 47° E–S 47° W.
126 „ S 75° E	The land area was 140 km long and 77 km wide.

TABLE II. *(Continued.)*

Earthquake.		Intensity.	Position of earthq. origin.		Area of disturbance.		Direction of the major axis.
No.	Group.		Lat. N.	Long. E.	Semi-major axis. (km)	Semi-minor axis. (km)	
147	V	*Weak.*	35° 44′	141° 5′	110	110	—
152	II	„	35 58	139 55	56	34	N 30° W–S 30° E
154	IV	*Strong.*	35 24	139 51	—	—	—
155	III	*Weak.*	35 58	139 30	87	87	—
156	III	*Slight.*	35 51	139 46	80	80	—
158	III	*Weak.*	36 0	139 30	80	80	—
161	IV	„	35 24	139 34	46	29	—
163	IV	*Strong.*	35 27	139 26	46	36	N 51° E–S 51° W
169	IV	*Slight.*	—	—	27	19	—
171	IV	*Strong.*	35 34	139 47	200	115	—
172	V	„	36 0	141 0	—	—	—
173	V	*Weak.*	36 0	141 30	—	—	—
174	V	*Strong.*	36 16	141 23	—	—	—
176	V	„	36 40	141 30	—	—	—
177	IV	„	35 27	139 46	150	90	N 23° W–S 23° E

Distance and direction of earthquake origin from Tokyo.		REMARK.
118 km,	E	——
34 ,,	N 20° E	——
29 ,,	S 15° E	This was a large earthquake, whose NEN and WSW radii of propagation were respectively 425 and 300 km, the origin being in Tokyo Bay. The radius of the *strong* motion area was 135 km and that of the violent motion area 48 km.
40 ,,	N 36° W	The area was nearly circular.
21 ,,	N 7° W	,, ,, ,,
44 ,,	N 35° W	,, ,, ,,
35 ,,	S 35° W	——
41 ,,	S 53° W	This was a small earthquake, felt *strongly* in the E part of Sagami.
—	SWS	The origin was probably in the Tokyo Bay.
—	—	This was an extensive earthquake, whose SW and NE radii of propagation were respectively 100 and 300 km; the origin being in the immediate vicinity of Tokyo. The area of *strong* motion was an ellipse whose two axes were respectively 130 and 57 km, and whose major axis was in the direction N 63° E–S 63° W.
115 ,,	N 70° E	This was an extensive earthquake, whose NE and SW radii of propagation were each 225 km. The motion was felt *strongly* in a small elliptical area (axes 64 and 23 km) about the mouth of the Tone-*gawa*.
162 ,,	N 78° E	The land area was 360 km long and 180 km wide. This earthquake was much similar to No. 172, except that the *intensity* was less.
160 ,,	N 62° E	An extensive earthquake, whose N and SWS radii of propagation were respectively 270 and 330 km, the land area being 510 km long and 170 km wide. The area of *strong* motion was a narrow zone, 155 km long and 22 km wide, which extended from the SE corner of Iwaki down to the NE corner of Shimosa.
195 ,,	N 54° E	An extensive earthquake, whose N and SW radii of propagation were respectively 330 and 300 km, the land area being 450 km long and 170 km wide. The motion was *strong* in the S portion of Iwaki and in the NE portion of Shimotsuke.
23 ,,	S	The motion was felt *strongly* along the western coast of the Tokyo Bay between Tokyo and Yokohama.

TABLE II. (*Continued.*)

Earthquake. No.	Earthquake. Group.	Intensity.	Position of earthq. origin. Lat. N.	Position of earthq. origin. Long. E.	Area of disturbance. Semi-major axis. (km)	Area of disturbance. Semi-minor axis. (km)	Direction of the major axis.
178	IV	*Slight.*	35° 26′	139° 51′	48	28	N 70° W–S 70° E
179	II	*Weak.*	36 10	139 51	100	80	N 38° E–S 38° W
180	II	,,	36 11	139 38	104	79	N 42° E–S 42° W
181	II	*Slight.*	—	—	57	36	N 43° E–S 43° W
182	IV	*Strong.*	35 42	139 12	160	160	——
184	VII	*Weak.*	35 0	139 25	120	120	——
186	II	*Slight.*	—	—	—	—	——
188	II	,,	36 5	140 0	55	40	N 40° E–S 40° W
189	V	*Weak,*	37 0	142 0	—	—	——
192	V	*Strong.*	36 25	141 0	150	150	——
194	II	*Slight.*	36 0	140 20	70	70	——
195	III	,,	35 46	140 7	81	37	N 23° W–S 23° E
197	VII	*Violent.*	35 28	136 57	310	157	N 70° E–S 70° W
203	V	*Slight.*	—	—	—	—	N 30° E–S 30° W
207	V	,,	—	—	137	77	N 38° E–S 38° W

Distance and direction of earthquake origin from Tokyo.			REMARK.
26	km,	S 10° E	——
58	„	N 8° E	——
59	„	N 13° W	——
53	„	N 43° E	——
120	„	S 30° W	The area was nearly circular.
74	„	S 23° W	„ „ „ „
—		—	This was a small earthquake, the origin and the area being nearly the same as those of No. 188.
55	„	N 40° E	——
260	„	N 60° E	This was an extensive earthquake, felt along the coast between N part of Iwaki and E portion of Musashi.
137	„	N 54° E	The motion was felt *strongly* in the N half of Hitachi; Tokyo being on the SWS edge of the disturbed area.
60	„	N 55° E	The area was nearly circular.
37	„	N 60° E	——
260	„	S 83° W	This was an extensive earthquake, whose E and W radii of propagation were respectively 300 and 330 km; the origin being in the vicinity of Koori in the N part of Owari. The mean radii of the areas of *violent*, *strong* and *weak* motion were respectively 34, 100 and 158 km.
160	„	N 60° E	The land area was 200 km long and 80 km wide.
		——	——

TABLE II. (*Continued.*)

Earthquake.		Intensity.	osition of earthq. origin.		Area of disturbance.		Direction of the major axis.
No.	Group.		Lat. N.	Long. E.	Semi-major axis. (km)	Semi-minor axis. (km)	
208	II	—	36° 22′	140° 16′	103	36	N 30° E–S 30° W
209	V	—	36 30	142 0	—	—	——
210	V	—	36 10	141 0	—	—	——
211	II	—	—	—	55	42	——
212	V	—	35 42	141 0	—	—	——
214	V	*Strong.*	36 30	141 25	320	75	N 40° E–S 40° W
215	VII	,,	34 35	138 30	315	62	N 80° E–S 80° W
216	II	—	36 17	139 57	73	73	——
219	II	—	36 5	140 11	103	55	N 10° W–S 10° E
220	IV	—	—	—	57	36	N–S

Distance and direction of earthquake origin from Tokyo.	REMARK.
100 km, N 30° E	The area was a long regular ellipse, Tokyo being on the SW end of the major axis.
230 „ N 65° E	The land area was 250 km long and 63 km wide, Tokyo being at the SW edge of it.
120 „ N 65° E	The land area was 96 km long and 23 km wide.
53 „ N 25° E	——
107 „ E	The shock was felt only in the vicinity of the Inubō-*zaki*.
170 „ N 5 8° E	The motion was felt *strongly* in the SE portion of Iwaki and the NE part of Hitachi.
160 „ S 42° W	The origin was at the mouth of the Suruga Bay, and the motion was felt *strongly* in the SE portion of Totomi, SW part of Suruga and W half of Izu.
73 „ N 10° E	The area was nearly circular.
60 „ N 40° E	Tokyo was at the SW edge of the area.
36 „ E	Tokyo was at the W end of the minor axis.

4. Radii of Propagation and Distances of the Earthquake Origins from Tokyo.

Table III gives, for each of the earthquakes of Groups II to VII, ıe mean radius (r) of propagation and the distance (d) between 'okyo and the origin of disturbance. The average values of r and d r the different Groups are as follows.—

Group.	Average r.	Average d.	Average ratio, $\frac{r}{d}$.
II	92 km.	61 km.	1.5
III	58	41	1.4
IV	76	43	1.8
V	203	143	1.4
VI	420	414	1.0
VII	176	194	About 1.

Thus the average ratio of $^r/_d$ is greatest for Group IV. Now this ratio is, as discussed below, approximately proportional to the amplitude of vibration at a given observing station. Consequently the shaking in Tokyo will, on average, be greatest in cases of the earthquakes belonging to group IV. The values of the ratio $^r/_d$ are, however, not markedly different for the three groups II, III and IV. The ratio is nearly unity for the two groups VI and VII ; that is to say, in cases of strong earthquakes belonging to these two groups, Tokyo is generally on, or near the boundary of the area of disturbance.

What has been said above relates to ordinary, or non-destructive, earthquakes. Extensive and strong earthquakes seem to occur most frequently from zone V.

TABLE III.—MEAN RADII OF PROPAGATION AND DISTANCES OF THE EARTHQUAKE ORIGINS FROM TOKYO.

r=Mean radius of propagation, in km.

d=Distance of earthquake origin from Tokyo, in km.

Group II.			Group III.			Group IV.		
No.	*r*	*d*	No.	*r*	*d*	No.	*r*	*d*
20	96	85	14	51	52	10	63	49
28	155	60	17	89	80	11	22	26
29	60	55	49	34	32	18	40	37
30	92	78	70	305	29	21	92	22
37	68	68	115	25	23	34	43	43
38	76	80	118	54	68	62	115	63
50	84	60	119	27	30	79	55	57
53	52	44	121	45	52	81	36	32
59	65	53	124	24	26	82	58	63
60	62	51	125	92	53	84	87	56
61	93	39	142	82	29	86	90	52
65	240	69	155	87	40	89	24	21
69	60	52	156	80	21	92	53	51
75	47	48	158	80	44	113	98	110
76	59	41	195	60	37	114	23	21
78	265	56	**Mean.**	**58**	**41**	126	44	38
83	128	58				137	32	41
123	105	62				154	360	29
143	200	38				161	38	35
152	45	34				163	41	41
179	90	58				169	23	—
180	92	59				171	160	0
181	47	53				177	120	23
186	—	—				178	38	26
188	48	55				182	160	120
194	70	60				220	47	36
208	70	100				**Mean.**	**76**	**43**
211	49	53						
216	73	73						
219	79	60						
Mean.	**92**	**61**						

TABLE III. (*Continued.*)

Group V.			Group VI.			Group VII.		
No.	*r*	*d*	No.	*r*	*d*	No.	*r*	*d*
13	380	125	48	600	600	94	164	280
15	195	190	56	390	390	184	120	74
19	185	125	103	—	270	197	234	260
23	235	160	134	—	430	215	190	160
39	—	150	138	270	380	Mean.	**176**	**194**
42	57	90	Mean.	**420**	**414**			
43	255	107						
44	135	140						
45	—	—						
46	225	130						
54	62	95						
55	—	130						
71	100	140						
77	—	120						
	—	110						
97	—	144						
102	90	100						
104	200	130						
117	50	—						
122	185	150						
131	—	190						
144	—	126						
147	110	118						
172	225	115						
173	—	162						
174	300	160						
176	315	195						
189	—	260						
192	150	137						
203	—	160						
207	107	—						
209	—	230						
210	—	120						
212	—	107						
214	200	170						
Mean.	**203**	**143**						

5. Tabular Statement of the Results of the Earthquake Measurements.*

Tables IV to X give (*a*) for Hitotsubashi and (*b*) for Hongo respectively the principal elements of motion for the earthquakes of the seven different groups I to VII; the detailed analysis of the seismograms being contained in the *Publications* No. 10. The arrangement of the tables is as follows.—

(1) Earthquake Number.

Horizontal Motion.

(2) Total duration.

(3) Duration of the preliminary tremor.

(4) General direction of motion.

(5) Maximum horizontal motion.

(6) Direction of max. hor. motion.

(7) Period " " " "

(8) Maximum velocity.

(9) Maximum acceleration.

(10) Average period of vibration in the EW component.

(11) " " " " NS "

(Sometimes the average period deduced from the combination of the two components are given; this being distinguished by being enclosed within brackets.)

(12) Average period of the *ripples*.

Vertical Motion.

(13) Duration.

(14) Maximum vertical motion.

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* Cases of mere *tremors* not included.

(15) Period of max. vert. motion.

(16) Average period of vibration.

Table XI gives the following elements of earthquake motion as observed at the Central Meteorological Observatory :—

(1) Earthquake Number and Group.

(2) Duration of horizontal motion.

(3) Maximum ,, ,,

(4) Period of maximum hor. motion.

(5) Direction ,, ,, ,, .

(6) Maximum vertical motion.

(7) Period of max. vert. motion.

(8) Character of motion.

TABLE IV.—GROUP I; EARTHQUAKES OBSERVED

No. of Earth-quake.	Duration of		General direction of motion.	Horizontal		
				Maximum		
	Eqke. (s).	Prel. Trem. (s).		2a (mm)	Direction.	T_a (s).
12	—	—	E-W.	0.3	—	0.8
25	60	—	E-W.	0.2	—	0.8
26	—	—	SE-NW.	—	—	—
27	—	—	ENE-WSW.	—	—	—
31	85	—	ESE-WNW.	0.2	—	0.8
35	120	—	——	0.2	—	0.8
36	83	—	——	0.1	—	0.7
40	—	—	E-W.	Small.	—	—
52	40	—	N-S.	0.1	—	0.45
58	120	—	E-W.	0.4	—	0.84
67	40	—	E-W.	0.38	—	0.83
93	80	—	——	0.83	—	0.9
100	100	—	E-W.	0.75	E-W.	0.8
101	100	—	E-W.	0.83	—	0.72
105	100	—	——	0.2	—	0.88
116	40	—	E-W.	0.25	—	—
128	250	—	——	0.36	—	2.8
129	120	—	E-W.	0.75	—	0.87
130	60	—	E-W.	0.4	—	0.95
132	170	—	E-W.	0.63	—	0.85
135	45	—	E-W.	0.5	—	0.92
136	—	—	N-S.	—	—	—
141	60	—	E-W.	0.2	—	0.8
146	40	—	E-W.	0.1	—	0.82
148	60	Short.	E-W.	0.38	E-W.	0.47
150	60	8	E-W.	0.38	—	0.56
167	80	—	E-W.	0.25	—	0.65

ONLY IN TOKYO. (*a*). ***Hitotsubashi.***

Component.					Vertical Component.			
motion.		Average period.		Average period of *ripples* (s).	Duration (s).	Maximum motion.		Average period (s).
$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	EW (s).	NS (s).			2a (mm).	T_0 (s).	
1.2	9.2	—	0.72	—	—	Small.	—	—
0.8	6.2	0.8	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
0.8	6.2	(0.71)		—	—	—	—	—
0.8	6.2	(0.78)		—	—	—	—	—
0.5	4.0	—	—	—	—	—	—	—
—	—	0.64	—	—	—	—	—	—
0.7	10.0	—	0.52	—	—	—	—	—
1.5	11.0	0.85	—	—	—	—	—	—
1.4	10.0	0.78	—	—	—	—	—	—
2.9	20.0	(0.98)		—	—	—	—	—
2.9	22.0	0.77	1.2	—	—	—	—	—
3.6	31.0	0.74	0.93	—	—	—	—	—
0.7	5.0	0.79	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
0.4	0.9	—	—	—	—	—	—	—
2.7	19.2	0.85	0.65	—	—	—	—	—
1.3	8.5	0.9	—	—	—	—	—	—
2.3	16.5	0.8	—	—	—	—	—	—
1.7	12.0	0.94	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
0.8	6.1	0.86	—	—	—	—	—	—
0.4	2.9	0.81	0.86	—	—	—	—	—
2.5	34.0	—	—	—	—	—	—	—
2.1	23.9	0.58	—	—	—	—	—	—
1.2	11.6	0.69	—	—	—	—	—	—

TABLE IV. (*Continued.*) GROUP I; EARTHQUAKES

No. of Earthquake.	Duration of		General direction of motion.	Horizontal		
				Maximum		
	Eqke. (s).	Prel. Trem. (s).		2a (mm).	Direction.	T_0 (s).
24	—	—	SES-NWN.	—	—	—
25	70	—	N-S.	0.2	—	0.5
31	45	—	——	0.2	—	0.4
51	40	—	——	0.1	—	0.5
58	25	—	N-S.	0.12	—	0.52
135	15	—	N-S.	0.08	—	about 0.26
139	—	—	N-S.	—	—	—
145	120	—	——	0.4	—	1.4
167	20	—	——	—	—	—
190	50	—	N-S.	0.2	—	1.1
213	15	—	——	0.1	—	—

OBSERVED ONLY IN TOKYO. (*b*). ***Hongo.***

Component.					Vertical Component.			
motion.		Average period.		Average period of *ripples*.(s)	Duration (s).	Maximum motion.		Average period (s).
$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	EW (s).	NS (s).			2a (mm).	T_0 (s).	
—	—	—	—	—	—	—	—	—
1.3	15.8	—	0.46	—	—	—	—	—
1.6	24.7	(0.59)		—	10	—	—	0.03
0.6	7.9	—	—	—	—	—	—	—
0.7	8.7	—	0.46	—	—	—	—	—
1.0	23.3	(0.26)		—	15	0.038	0.18	0.18
—	—	—	0.5	0.24	—	—	—	0.2
0.9	4.0	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
0.6	3.3	—	1.0	—	—	—	—	—
—	—	—	—	0.21	Short.	Small.	—	—

TABLE V.—GROUP II EARTHQUAKES.

No. of Earthquake.	Duration of		General direction of motion.	Horizontal Maximum		
	Eqke. (s).	Prel. Trem. (s).		2a (mm).	Direction.	T_o (s).
21	180	—	N–S.	—	—	—
28	—	—	N–S.	2.8	—	—
29	—	—	E–W, N–S.	0.3	—	—
38	100	—	N–S.	0.35	—	0.9
50	30	—	N–S.	0.25	N–S	0.62
59	100	—	E–W.	0.4	—	0.7
61	—	—	E–W.	0.32	—	0.86
65	150	—	——	2.0	E–W	0.77
76	60	—	E–W.	0.35	—	0.75
78	240	10	——	2.2	—	0.97
83	180	—	E–W.	1.8	—	0.94
123	160	10	E–W.	1.2	SW	0.77

TABLE V.—(*Continued.*)

20	70	—	E–W.	0.16	—	0.6
21	57	—	N–S.	0.26	—	—
28	100	3	N–S.	2.4	N 15° W	0.8
29	40	—	——	0.2	—	0.7
50	35	—	E–W.	0.15	—	0.5
60	16	—	E–W.	0.1	—	0.23
61	30	—	——	0.32	—	0.3
65	110	—	——	1.4	NEN	0.71
78	140	—	E–W.	0.74	—	0.78
123	40	—	——	0.54	SW	—
179	25	—	——	0.26	—	0.49
194	120	—	——	0.4	—	—
208	50	—	——	—	—	—
216	30	—	E–W.	0.24	—	—
219	30	—	——	0.1	—	0.20

(*a*). ***Hitotsubashi.***

Component.					Vertical Component.			
motion.		Average period.		Average period of *ripples* (s).	Duration (s).	Maximum motion.		Average period (s).
$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	EW (s).	NS (s).			2a (mm).	T_0 (s).	
—	—	—	0.63	—	40	0.3	0.5	0.45
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
1.2	8.5	—	0.85	—	—	—	—	—
1.3	12.9	—	0.70	—	—	—	—	—
1.8	16.0	0.71	—	—	—	—	—	—
1.2	9.0	—	—	—	—	Small.	—	—
8.2	67.0	0.75	0.77	—	50	0.6	0.65	0.49
1.6	14.0	0.76	—	—	—	—	—	—
7.1	46.1	0.83	—	—	120	0.4	0.70	0.64
6.0	40.0	0.84	—	—	25	0.2	0.62	0.63
4.9	40.0	0.71	—	—	30	0.2	0.4	—

(*b*). ***Hongo.***

0.8	8.8	—	—	—	—	0.06	0.5	—
—	—	—	0.47	0.18	13	0.16	—	0.18
9.4	74.0	—	0.53	0.24	50	0.11	0.25	—
0.9	8.1	—	—	—	—	—	—	—
0.94	12.0	—	—	—	—	—	—	—
1.4	37.3	0.23	—	—	Short.	—	—	0.17
3.4	72.0	{0.18 0.37	0.19	—	12	0.07	0.26	{0.12 0.16
6.2	55.0	0.57	0.78	0.18	25	0.14	0.24	0.2
3.0	25.0	0.54	0.85	—	20	0.1	0.37	0.18
—	—	—	—	0.22	20	—	—	0.17
1.7	21.4	—	0.6	—	20	—	—	0.23
—	—	1.3	1.1	0.21	—	Small.	—	—
—	—	—	—	—	—	—	—	—
—	—	0.43	—	0.20	—	—	—	—
1.6	49.3	—	—	0.18	—	—	—	—

TABLE VI.—GROUP III EARTHQUAKES.

No. of Earth-quake.	Duration of		General direction of motion.	Horizontal		
				Maximum		
	Eqke. (s).	Prel. Trem. (s).		2a (mm).	Direction.	T_0 (s)
5	100	—	E-W.	0.2	—	0.8
14	120	—	——	0.64	—	1.1
49	25	—	N-S.	0.25	—	0.6
115	—	—	E-W.	0.1	—	—
142	70	—	E-W.	0.38	E	0.87
155	100	—	E-W.	0.3	—	0.65

TABLE VI.—(*Continued.*)

3	40	—	——	—	—	—
5	50	—	N-S.	—	—	—
14	—	—	E-W.	—	—	—
17	65	—	——	0.05	—	0.6
124	20	—	——	0.14	—	0.34

(*a*). ***Hitotsubashi.***

Component.					Vertical Component.			
motion.		Average period.		Average period of *ripples* (s).	Duration (s).	Maximum motion.		Average period (s).
$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	EW (s).	NS (s).			2a (mm).	T_0 (s).	
0.8	6.2	0.83	0.78	—	—	—	—	—
1.8	10.4	0.83	—	—	—	—	—	—
1.3	13.0	0.78	0.70	—	—	—	—	—
—	—	—	—	—	—	—	—	—
1.4	9.9	0.81	0.84	—	—	—	—	—
1.4	14.0	(0.74)		—	—	—	—	—

(*b*). ***Hongo.***

—	—	—	—	—	30	—	—	0.42
—	—	—	0.43	—	—	—	—	—
—	—	—	—	—	—	—	—	—
0.3	2.7	1.4	0.50	—	—	—	—	—
1.3	2.4	—	—	—	—	—	—	—

TABLE VII. GROUP IV EARTHQUAKES.

No. of Earthquake.	Duration of		General direction of motion.	Horizontal Maximum		
	Eqke. (s)	Prel. Trem. (s).		2a (mm).	Direction.	T_0 (s).
10	50	—	——	0.21	—	0.54
21	180	—	N-S.	—	—	—
62	100	—	E-W.	0.4	—	0.74
82	60	—	E-W.	0.25	—	0.71
84	100	—	——	0.3	—	0.88
86	120	—	E-W.	1.0	—	0.70
92	30	—	E-W.	0.25	—	0.57
126	60	—	E-W.	0.25	—	0.82
137	120	—	E-W.	0.63	—	0.79
161	25	—	E-W.	0.13	—	0.51

TABLE VII.—(*Continued.*)

7	90	—	——	—	—	—
10	—	—	N-S.	0.2	—	0.45
62	70	—	——	—	—	—
84	60	—	——	0.16	—	0.22
86	70	—	——	0.2	—	0.6
154	480	11	——	7.2	S 48° E	1.3
171	80	—	E-W.	0.7	—	0.25
177	80	—	E-W.	0.3	—	0.26
182	540	100	——	17.0	—	2.8
220	15	—	——	0.1	—	0.25

(*a*). ***Hitotsubashi.***

Component.					Vertical Component.			
motion.		Average period.		Average period of *ripples* (s).	Duration (s).	Maximum motion.		Average period (s).
$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	EW (s).	NS (s).			2a (mm).	T_0 (s).	
1.2	14.2	0.52	0.55	—	—	—	—	—
—	—	—	0.63	—	40	0.3	0.5	0.45
1.7	15.0	0.85	—	—	—	Small.	—	—
1.1	10.0	0.74	—	—	—	—	—	—
1.1	8.1	0.78	—	—	—	—	—	—
4.5	41.0	(0.76)		—	—	Small.	—	—
1.4	16.0	—	—	—	—	—	—	—
1.0	7.1	0.77	—	—	—	—	—	—
2.5	20.0	0.77	—	—	—	—	—	—
0.8	9.9	0.62	—	—	—	—	—	—

(*b*). ***Hongo.***

—	—	0.72	0.44	—	—	—	—	0.17
1.4	19.5	—	0.44	—	—	—	—	0.16
—	—	—	—	—	—	Small.	—	—
2.3	66.0	2.0 ?	—	0.23	10	0.06	0.23	0.23
0.52	2.7	1.3	{1.2 2.1	0.44	—	—	—	—
17.4	84.1	(1.07)		—	220	1.0	0.96	0.39
9.0	221.0	1.2	0.75	0.28	60	0.23	0.44	{0.36 0.65
3.6	87.6	1.6	0.79	0.19	40	0.06	0.32	{0.27 0.55
19.0	42.8	6.5	—	—	360	1.5	0.31	—
1.3	31.5	—	0.44	0.17	—	—	—	—

TABLE VIII. GROUP V EARTHQUAKES.

No. of Earth-quake.	Horizontal					
	Duration of		General direction of motion.	Maximum		
	Eqke. (s).	Prel. Trem. (s).		2a (mm).	Direction.	T_o (s).
2	140	—	——	1.5	—	0.83
4	100	—	——	—	—	—
19	180	—	{ENE-WSW. {ESE-WNW.	1.7	S 70° W	0.84
23	100	—	E-W.	0.64	SE	0.96
39	120	—	N-S.	0.6	—	0.79
42	60	—	E-W.	0.38	E-W	0.91
43	—	—	{ E-W. {NEN-SWS.	5.0	—	—
71	110	—	——	0.35	—	0.91
97	50	—	E-W.	0.43	—	0.73
122	120	7	.E-W.	0.7	—	0.66
131	180	—	E-W.	0.75	—	0.75

TABLE VIII.—(*Continued.*)

4	80	—	——	—	—	—
13	270	15.0	E-W.	15.0	N 84° E	3.0
19	116	1.2	{ENE-WSW. {ESE-WNW.	0.5	—	0.5
23	90	2.0	N-S.	0.6	S	1.3
39	65	—	N-S.	0.32	—	0.48
43	130	3.6	{ENE-WNW. {NEN-SWS.	2.0	W 20° N	1.3
44	—	—	E-W.	0.2	—	—
46	115	—	E-W, N-S.	0.5	—	0.57
122	70	—	——	0.6	S	—
172	100	—	——	0.8	—	0.69
174	200	—	——	1.2	—	1.13
176	240	—	E-W.	{0.6 {1.1	—	{1.43 {2.1
192	60	—	——	0.2	—	0.67
207	180	60	N-S.	0.56	—	1.12
212	30	—	——	0.14	—	0.84
214	90	—	——	0.1	—	0.56

(*a*). ***Hitotsubashi.***

Component.					Vertical Component.			
motion.		Average period.		Average period of *ripples* (s).	Duration (s).	Maximum motion.		Average period (s).
$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	EW (s).	NS (s).			2a (mm).	T_0 (s).	
5.7	43.0	(0.79)		—	80	—	—	—
—	—	0.94	—	—	—	—	—	—
6.3	47.6	0.77	—	—	—	—	—	—
2.1	13.7	0.83	—	—	—	—	—	—
2.4	19.0	—	0.83	—	—	—	—	—
1.3	9.1	0.89	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
1.2	8.0	0.87	0.89	—	—	—	—	—
1.9	16.0	0.71	—	—	—	—	—	—
3.3	31.0	0.78	—	—	40	0.18	0.38	—
3.1	25.3	0.77	—	—	—	—	—	—

(*b*). ***Hongo.***

—	—	0.69	0.43	—	—	—	—	0.19
15.7	33.0	1.3	0.57	—	80	0.48	0.61	0.16
3.1	39.5	{0.48 {0.93	0.48	—	—	—	—	—
1.4	7.0	0.69	0.45	0.16	45	0.6	0.21	0.21
2.1	28.0	0.77	0.43	0.17	22	0.06	0.19	0.17
4.8	23.0	0.86	0.47	0.15	34	0.18	0.43	0.29
—	—	—	—	—	—	—	—	—
2.8	31.0	0.81	0.48	0.18	26	0.06	0.4	0.23
—	—	—	0.52	—	20	0.13	0.38	0.28
—	—	0.75	1.0	—	40	0.2	0.93	0.66
3.3	18.5	1.24	1.12	—	65	1.4	0.82	{0.12 {0.83
{1.3 {1.6	{5.8 {4.9	2.32	1.19	0.49	60	0.01	0.51	0.54
0.9	8.8	—	—	—	—	—	—	—
1.6	8.7	—	1.13	—	90	0.06	0.32	—
0.5	3.9	—	0.88	—	—	—	—	—
0.6	8.8	0.55	—	0.20	70	0.06	0.19	0.57

TABLE IX. GROUP VI EARTHQUAKES.

No. of Earthquake.	Duration of Eqke. (s).	Duration of Prel. Trem. (s).	General direction of motion.	Horizontal Maximum 2a (mm).	Horizontal Maximum Direction.	Horizontal Maximum T_2 (s).
48	120	40	N-S, E-W.	1.0	—	0.57
56	120	—	——	0.45	—	0.78
103	180	—	E-W.	1.1	—	0.81
138	80	—	——	0.17	—	0.68

TABLE IX.—(*Continued.*)

9	220	—	——	—	—	—
48	—	—	——	—	—	—
56	100	—	N-S.	0.24	—	0.79
103	180	—	——	0.5	—	—

TABLE X. GROUP VII EARTHQUAKES.

1	220	—	——	5.0	—	1.8
94	60	—	E-W.	0.45	—	0.83

TABLE X.—(*Continued.*)

184	60	—	——	0.1	—	—
197	120	—	——	0.5	—	1.16
215	90	—	——	0.2	—	1.14

(*a*). ***Hitotsubashi.***

Component.					Vertical Component.			
motion.		Average period.		Average period of *ripples* (s)	Duration (s).	Maximum motion.		Average period (s).
$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	EW (s).	NS (s).			2a (mm).	T_0 (s).	
5.5	60.0	—	0.45	—	—	—	—	—
1.8	14.0	—	0.67	—	—	—	—	—
4.3	34.0	0.78	—	—	—	—	—	—
0.79	7.3	0.75	—	—	—	—	—	—

(*b*). ***Hongo.***

—	—	1.0	0.46	—	—	Small.	—	0.14
—	—	0.84	0.47	—	—	—	—	—
0.95	7.5	—	0.74	—	—	—	—	—
—	—	—	—	—	—	—	—	—

(*a*). ***Hitotsubashi.***

8.7	30.5	—	—	—	100	—	—	—
1.7	13.0	0 85	—	—	—	—	—	—

(*b*). ***Hongo.***

—	—	0.48	0.68	—	25	0.05	0.39	0.45
1.4	7.3	1.24	1.14	—	—	—	—	—
0.6	3.0	1.44	1.19	—	—	—	—	—

TABLE XI.—SUMMARY OF THE EARTHQUAKE OBSERVATIONS AT THE CENTRAL METEOROLOGICAL OBSERVATORY.

Earthquake.		Horizontal Motion.				Vert. motion.		Character.
No.	Group.	Duration.(s).	Max. 2a. (mm).	T_o (s).	Direction.	Max. 2a. (mm).	T_o (s).	
10	IV	10	0.4	0.7	E–W	Small.	—	Quick.
13	V	360	25.7	2.3	SE–NW	6.5	0.8	"
16	I	25	Small.	—	E–W	—	—	Gentle.
17	III	12	0.2	1.2	SW–NE	—	—	"
18	IV	180	0.2	0.3	E–W	—	—	Quick.
19	V	120	1.0	1.8	ESE–WNW	Small.	—	Gentle.
20	II	120	0.4	2.4	SE–NW	—	—	"
21	IV	45	0.2	0.5	SWS–NEN	—	—	Quick.
23	V	90	1.3	1.2	SES–NWN	—	—	"
24	I	15	Small.	—	—	—	—	—
27	I	150	0.3	2.0	SES–NWN	—	—	Gentle.
28	II	120	2.5	1.5	ESE–WNW	0.3	0.4	Quick.
29	II	10	Small.	—	—	—	—	"
31	I	10	0.25	0.6	E–W	—	—	Gentle.
33	I	15	Small.	—	—	—	—	—
35	I	60	0.2	2.0	SW–NE	—	—	Gentle.
39	V	60	0.4	1.8	ESE–WNW	—	—	"
41	I	15	Small.	—	E–W	Very small.	—	Quick.
42	V	10	"	—	N–S	—	—	Gentle.
43	V	228	13.0	3.7s	ESE–WNW	0.5	—	Quick.

TABLE XI.—*(Continued.)*

Earthquake.		Horizontal Motion.				Vert. motion.		Character.
No.	Group.	Duration.(s).	Max. 2a, (mm).	T_0 (s).	Direction.	Max. 2a. (mm).	T_0 (s).	
44	V	109	0.7	1.4	E-W	—	—	Gentle.
46	V	45	3.8	2.4	WSW-ENE	—	—	"
48	IV	60	1.6	2.1	SW-NE	—	—	"
49	III	10	Small.	—	NE-SW	—	—	Quick.
50	II	12	Very small.	—	E-W	—	—	—
52	I	25	Small.	—	N-S	—	—	Gentle.
53	II	30	Very small.	—	E-W	—	—	"
54	V	50	"	—	E-W	—	—	"
55	V	15	"	—	E-W	—	—	"
56	VI	90	0.7	3.2	N-S	—	—	"
57	I	10	Very small.	—	N-S	—	—	"
58	I	—	"	—	E-W	—	—	"
59	II	88	Small.	—	WSW-ENE	—	—	"
60	II	30	"	—	N-S	—	—	Quick.
61	II	25	0.4	0.2	NWN-SES	—	—	"
64	I	—	Very small.	—	—	—	—	Gentle.
65	II	120	1.2	0.7	SE-NW	0.5	0.3	Quick.
69	II	480	5.6	0.8	SE-NW	1.5	0.6	"
70	III	—	Very small.	—	E-W	—	—	Gentle.
71	V	120	0.2	1.5	SW-NE	—	—	"
76	II	10	0.2	0.5	NW-SE	—	—	Quick.
78	II	270	1.5	2.6	ESE-WNW	0.2	0.7	Gentle.
79	IV	60	Small.	—	E-W	—	—	"
83	II	180	1.5	1.3	WNW-ESE	Small.	—	"
84	IV	20	0.4	1.2	NWN-SES	—	—	"

TABLE XI.—(*Continued.*)

Earthquake.		Horizontal Motion.				Vert. motion.		Character.
No.	Group.	Duration. (s).	Max. 2a. (mm)	T_0 (s).	Direction.	Max. 2a. (mm).	T_0 (s).	
86	IV	100	0.3	0.8	SE-NW	—	—	Quick.
89	IV	20	0.2	0.8	E-W	—	—	,,
91	I	10	Small.	—	E-W	—	—	,,
93	I	180	,,	—	E-W	—	—	Gentle.
94	VII	60	,,	—	—	—	—	,,
97	V	180	0.6	2.4	SWS-NEN	—	—	,,
100	I	90	0.2	1.0	E-W	Very small.	—	,,
101	I	90	0.2	0.8	E-W	—	—	Quick.
103	VI	180	0.4	1.2	SWS-NEN	—	—	Gentle.
104	V	70	0.2	1.0	E-W	—	—	,,
108	I	30	Very small.	—	E-W	—	—	,,
114	IV	25	0.4	0.4	E-W	Small.	—	Quick.
115	III	30	Small.	—	E-W	—	—	—
116	I	20	Very small.	—	E-W	—	—	Gentle.
118	III	30	Small.	—	—	—	—	Quick.
120	I	30	,,	—	—	—	—	—
122	V	120	1.2	0.5	NEN-SWS	0.5	4.5	Quick.
123	II	60	0.3	0.8	E-W	—	—	,,
124	III	90	0.3	0.5	E-W	Small.	—	,,
125	III	270	1.9	0.4	SW-NE	0.5	0.5	,,
127	I	180	0.2	2.2	—	—	—	Gentle.
128	I	240	0.5	3.5	E-W	—	—	,,
129	I	90	0.3	1.8	WNW-ESE	—	—	,,
131	V	150	0.2	0.9	E-W	—	—	,,
134	VI	240	0.4	1.4	NW-SE	—	—	,,

TABLE XI.—(*Continued.*)

Earthquake.		Horizontal Motion.				Vert. motion.		Character.
No.	Group.	Duration.(s).	Max. 2a. (mm).	T_0 (s).	Direction.	Max. 2a. (mm).	T_0 (s).	
135	I	15	0.2	0.5	E–W	—	—	Quick.
137	IV	120	0.2	1.8	SE–NW	—	—	Gentle.
139	I	20	Small.	—	N–S	—	—	„
141	I	35	0.2	1.7	E–W	—	—	„
142	III	12	0.5	0.3	SW–NE	Small.	—	Quick.
143	II	120	1.1	1.0	SW–NE	0.5	0.3	„
144	V	120	0.8	1.5	E–W	—	—	Gentle.
151	I	5	Small.	—	N–S	—	—	—
152	II	10	„	—	N–S	—	—	Quick.
154	IV	372	20.3	2.2	NW–SE	3.7	6.0	„
155	III	120	0.2	—	SW–NE	—	—	—
156	III	120	Small.	—	E–W	—	—	—
158	III	80	„	—	SE–NW	—	—	—
159	I	15	„	—	N–S	—	—	Gentle.
161	IV	15	„	—	E–W	—	—	Quick.
162	I	20	„	—	S–N	—	—	Gentle.
163	IV	30	Very small.	—	—	—	—	„
164	I	15	Small.	—	N–S	—	—	„
165	I	13	„	—	N–S	—	—	„
166	I	30	0.2	0.6	N–S	—	—	—
168	I	—	Small.	—	N–S	—	—	—
171	IV	90	4.1	0.6	ESE–WNW	0.6	0.5	Quick.
172	V	75	0.5	0.5	SE–NW	Small.	—	Gentle.
173	V	20	0.2	0.2	E–W	—	—	Quick.
174	V	240	3.8	2.5	SES–NWN	0.2	0.6	Gentle.

TABLE XI.—(*Continued.*)

Earthquake.		Horizontal Motion.				Vert. motion.		Character.
No.	Group.	Duration.(s).	Max. 2a. (mm).	T_o (s).	Direction.	Max. 2a. (mm).	T_o (s).	
176	V	120	1.2	0.7	SW-NE	Very small.	—	Gentle.
177	IV	90	1.5	0.7	SE-NW	0.2	0.3	Quick.
179	II	50	0.3	0.5	SW-NE	Very small.	—	,,
182	IV	—	0.8	1.0	ESE-WNW	0.2	0.7	Gentle.
184	VII	—	0.3	0.9	SE-NW	—	—	,,
188	II	50	0.2	0.6	SW-NE	—	—	,,
189	V	90	0.2	0.6	E-W	Very small.	—	,,
192	V	30	Small.	—	E-W	,,	—	,,
193	I	20	,,	—	E-W	,,	—	—
194	II	60	0.4	0.5	NEN-SWS	,,	—	Quick.
195	III	30	Small.	—	N-S	,,	—	Gentle.
197	VII	120	0.6	2.0	SES-NWN	—	—	,,
202	I	30	Small.	—	—	—	—	—
204	I	120	Very small.	—	E-W	—	—	—
205	I	15	Small.	—	E-W	—	—	—
207	V	120	0.4	0.8	SE-NW	—	—	Quick.
208	II	25	0.2	0.5	E-W	—	—	Gentle.
212	V	50	Small.	—	—	—	—	,,
213	I	30	,,	—	SE-NW	—	—	Quick.
214	V	90	0.5	0.6	SE-NW	Small.	—	,,
215	VII	60	0.5	2.5	E-W	—	—	Gentle.
216	II	40	0.3	0.5	E-W	Very small.	—	Quick.
219	II	35	Small.	—	N-S	—	—	,,
220	IV	10	,,	—	E-W	—	—	Gentle.

6. Summary of the Observations at Hitotsubashi.

The average values of the elements of earthquake motion at Hitotsubashi for the different groups are collected in Table XII, the general mean results being as follows.

Horizontal Motion (64 earthquakes) :—

Duration = 101 sec.

Maximum Motion = 0.70 mm.

Period of max. motion = 0.77 sec.

Maximum velocity = 2.4 $^{mm}/_{sec.}$

Maximum acceleration = 20.0 $^{mm}/_{sec.^2}$

Average period = 0.76 sec.

Vertical motion (10 earthquakes) :—

Duration = 58 sec.

Maximum motion = 0.22 mm.

Period of max. motion = 0.54 sec.

Average period = 0.53 sec.

Thus it seems that the mean value of the period of the maximum vibration, both in the horizontal and the vertical component, seems to be practically identical with that of the average period. The case might be different if we take only strong earthquakes.

The horizontal motion lasts twice as long as the vertical motion, the max. $2a$ and T_0 of the former being respectively about 3 and 0.7 times those for the latter.

TABLE XII.—SUMMARY OF THE HITOTSUBASHI OBSERVATIONS.

Group.	Horizontal Component.						Vertical Component.			
	Duration. (sec).	Maximum motion.				Average period. (sec).	Duration. (sec).	Maximum motion.		Average period. (sec).
		2a (mm).	T_o (sec).	V (mm/s).	A (mm/s²).			2a (mm).	T_o (sec).	
I	87	0.36	0.77	1.51	12.6	0.79	—	—	—	—
II	133	1.09	0.81	3.7	28.2	0.75	53	0.3	0.57	0.55
III	83	0.31	0.80	1.34	10.7	0.79	—	—	—	—
IV	85	0.38	0.70	1.70	15.7	0.72	40	0.1	0.5	0.45
V	116	1.21	0.82	3.03	23.6	0.82	60	0.2	0.38	—
VI	125	0.68	0.71	3.1	28.8	0.66	—	—	—	—
VII	140	2 73	0.83*	5.2	21.8	0.85	100	—	—	—
Average.	101 sec.	0.70 mm.	0.77 sec.	2.4 mm/s.	20 mm/s²	0.77 sec.	58 sec.	0.22 mm.	0.54 sec.	0.53 sec.

(* In this case, there was also a period of 1.8 sec)

7. Summary of the Observations at Hongo.

Table XIII gives the mean elements of motion at Hongo for the seven Groups separately, the general average values of the duration and the max. 2a being as follows.—

Duration of horizontal motion = 96 sec.

Maximum horizontal motion = 0.79 mm.

Duration of vertical motion = 51 sec.

Maximum vertical motion = 0.22 mm.

Thus at Hongo the horizontal motion lasts twice as long as the vertical ; the range of motion of the former being also nearly 4 times larger than that of the latter.

The period of vibration is not so uniform as at Hitotsubashi, there existing evidently several different sets of waves. The following are classified lists of the mean values of the different periods of vibration at Hongo.

PERIODS OF HORIZONTAL MOTION.

Group.	Period of max. vibration.				Average period.				Period of *ripples*.	
	T_o'	T_o''	T_o'''	T_o''''	T'	T''	T'''	T''''	T_1	T_2
	sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.
I	0.26	0 48	1.25	—	0.26	0.50	1.00	—	0.23	—
II	0.24	0.65	—	—	0.20	0.57	1.20	—	0.20	—
III	0.34	0.60	—	—	—	0.47	1.40	—	—	—
IV	0.25	0.53	1.30	2.80	—	0.60	1.25	2.10	0.22	0.44
V	—	0.62	1.26	2.10	—	0.60	1.13	2.32	0.17	0.49
VI	—	0.79	—	—	—	0.56	0.92	—	—	—
VII	—	—	1.15	—	—	0.58	1.26	—	—	—
Mean.	0.26	0.60	1.25	2.60	0.22	0.57	1.18	2.20	0.20	0.47

PERIODS OF VERTICAL MOTION.

Group.	Period of max. vibration.			Average period.		
	t_o'	t_o''	t_o'''	t'	t''	t'''
	sec.	sec.	sec.	sec.	sec.	sec.
I	0.18	—	—	0.19	—	—
II	0.28	0.50	—	0.18	—	—
III	—	—	—	—	0.42	—
IV	0.29	0.44	0.96	0.21	0.38	0.60
V	0.23	0.47	0.88	0.21	—	0.65
VI	—	—	—	0.14	—	—
VII	—	0.39	—	—	0.45	—
Mean.	0.25	0.46	0.91	0.20	0.41	0.63

From the above tables it will be seen that each component period shows no sign of variation with the distance between Tokyo and the earthquake origins.

With respect to the max. horizontal vibration there are essentially four periods, whose mean values are: $T_o'=0.26$s, $T_o''=0.60$s, $T_o'''=1.25$s, $T_o''''=2.6$s; the one most frequently occurring being T_o''. These four periods are roughly in the ratios of 1 : 2 : 4 : 8. With respect to the mean period of vibration, there are similarly four periods: $T'=0.22$s, $T''=0.57$s, $T'''=1.18$s, $T''''=2.2$s; these being nearly equal to T_o', T_o'', T_o''' and T_o'''' respectively.

In the case of the vertical vibration, we have essentially four kinds of waves, as follows:—period of maximum vibration, $t_o'=0.25$s, $t_o''=0.46$s, $t_o''''=0.91$s; average period, $t'=0.20$s, $t''=0.41$s, $t'''=0.63$s; the period most frequently occurring being t_o' and t'. These four sets of the periods are roughly in the ratios of 1 : 2 : 3 : 4.

With regard to the horizontal *ripples*, there are essentially two different periods: $T_1=0.20s$ and $T_2=0.47s$; the former being the predominating one.

It is to be observed that the T_1 and T_2 of the horizontal ripples are practically identical with the t' and t'' of the vertical motion. This seems to indicate that the horizontal ripples and the vertical vibrations belong, in some cases, to one and the same kind of waves, which is probably in a part of the character of surface waves.

The ripples is sometimes quite prominent, the T_0' and T' of the horizontal motion being practically identical with the periods of the ripples.

TABLE XIII.—SUMMARY OF THE OBSERVATIONS AT HONGO.

Group.	Horizontal Component.								Vertical Component.			
	Duration.	Maximum motion.				Average period.			Duration.	Maximum motion.		Average period.
	(sec.)	2a (mm).	T_a (s).	V (mm/s).	A (mm/s².)	E W. (s).	N S. (s).	*Ripples.* (s)	(sec).	2a (mm).	T_a (s).	(sec)
I	44	0.18	0.26 0.48 1.25	0.81	12.5		0.26 0.50 1.00	0.23	8	0.02	0.18	0.19
II	60	0.31	0.24 0.65	2.43	36.3	0.20 0.40 0.56 1.30	0.19 0.65 1.10	0.20	20	0.09	0.28 0.50	0.18
III	44	0.10	0.34 0.60	0.8	2.6	1.4	0.47	—	30	—	—	0.42
IV	165	1.27	0.25 0.53 1.30 2.80	6.8	69.3	0.72 1.30 6.50 2.00	0.57 1.15 2.10	0.22 0.44	138	0.48	0.29 0.44 0.96	0.21 0.38 0.60
V	122	1.59	0.62 1.26 2.10	2.8	18.0	0.70 1.16 2.32	0.52 1.11	0.17 0.49	50	0.20	0.23 0.47 0.88	0.21 0.65
VI	167	0.37	0.79	0.95	7.5	0.92	0.56	—	—	—	—	0.14
VII	93	0.27	1.15	1.00	5.2	0.48 1.34	0.68 1.17	—	25	0.05	0.39	0.45
Mean.	96	0.79	—	2.2	21.6	—	—	—	51	0.22	—	—

8. Comparison of Earthquake Motion at Hitotsubashi and at Hongo.

The Seismological Institute (Hongo) is situated on the higher part of the town where the ground is of hard clay. On the other hand, the Hitotsubashi Observatory stands on low and very soft soil, which is seismically one of the most sensitive places in Tokyo. From the comparison of the seismograms obtained at Hitotsubashi with those obtained at Tsukiji,* it was found that the seismic movements at the former place is even greater than that at the latter.

Table XIV gives the comparison of the earthquake motion in the 26 cases observed simultaneously at Hitotsubashi and Hongo. (In each of the three cases, namely, earthquakes Nos. 135,61 and 84, the motion at Hongo consisted simply, of ripples of quick period, while that at Hitotsubashi consisted of vibrations of the usual period. Consequently these three earthquakes have been excluded in deducing the mean values of the quantities T_0, V and A.) The mean results of the comparison is as follows.

	Hitotsubashi.	Hongo.	Ratio, $\frac{\text{Hitotsubashi}}{\text{Hongo}}$.
Duration.	1.19 sec.	0.72 sec.	1.7
Max. 2a.	1.07 mm.	0.56 mm.	1.9
T_0	0.87 sec.	0.63 sec.	1.4
V	3.5 mm/s	1.9 mm/s	1.8
A	24.9 mm/s²	20.4 mm/s²	1.2

Thus the duration at Hitotsubashi is 1.7 times longer than that at Hongo. Further the maximum motion and the period at the

* Tsukiji or *Made Ground* is the name of the portion of the city along the sea coast, to the right-hand side of the mouth of the Sumida, which was formerly under the sea.

former place are greater than those at the latter respectively in the ratios of 1.9 and 1.4. Consequently the maximum velocity and maximum acceleration at Hitotsubashi are greater than those at Hongo respectively in the ratios of 1.8 and 1.2. These results are nearly the same as those obtained by the late Professor Sekiya.*

The above comparison relates to non-destructive earthquakes. In destructive earthquakes, the period of principal vibrations will *not* be very quick and consequently will not much differ at Hitotsubashi and Hongo. In these cases, therefore, the V and A at Hitotsubashi will differ from the corresponding quantities at Hongo in a greater ratio than those here indicated.

Remark. Loose soft soil and hard compact ground considerably differ in their elastic qualities, but their specific gravities do not much differ from each other. Consequently the earthquake movements in a loose soft soil will, in general, be slower in period and greater in amplitude than those in a hard compact ground or rocky district.

The dependence of the intensity of earthquake motion on the nature of soil is very striking indeed. Thus, for example, on the occasion of the great Mino-Owari earthquake of Oct. 28th, 1891, the shock was very strong in the city of Hikone (province of Ōmi), where several houses and temples were entirely overthrown ; while on a neighboring hill the shock was much weaker, even *stone lanterns* (Japanese lamp posts for girdens) not being overturned.

The effect of earthquake motion will similarly be felt very severely in a valley district, where loose soil is superposed on a hard formation ; just as sand particles placed on a sounding plate are caused to jump up by the vibration of the latter.

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* Jour. Sc. Coll. Imp. Univ., Tokyo, Vol. II.

TABLE XIV.—COMPARISON OF EARTHQUAKE MOVEMENTS AT HITOTSUBASHI AND HONGO.

(HORIZONTAL COMPONENT.)

Group.	No.	Duration. (s).		Max. 2a (mm).		T_0 (sec).		V. $\left(\frac{mm}{s.}\right)$		A. $\left(\frac{mm}{s^2.}\right)$	
		Hit.	Hongo.	Hit.	Hongo.	Hit.	Hongo.	Hit.	Hongo.	Hit.	Hongo.
I	25	60	70	0.2	0.2	0.8	0.5	0.8	1.3	6.2	15.8
„	31	85	45	0.2	0.2	0.8	0.4	0.8	1.6	6.2	24.7
„	58	120	25	0.4	0.12	0.84	0.52	1.5	0.7	11.0	8.7
„	135	45	15	0.5	0.08	0.92	0.26	1.7	1.0	12.0	23.3
„	167	80	20	0.25	—	0.65	—	1.2	—	11.6	—
II	21	180	57	—	0.26	—	—	—	—	—	—
„	28	—	100	2.8	2.4	—	0.8	—	9.4	—	74.0
„	29	—	40	0.3	0.2	—	0.7	—	0.9	—	8.1
„	50	30	35	0.25	0.15	0.62	0.5	1.3	0.94	12.9	12.0
„	61	—	30	0.32	0.32	0.86	0.3	1.2	3.4	9.0	72.0
„	65	105	110	2.0	1.4	0.77	0.71	8.2	6.2	67.0	55.0
„	78	240	140	2.2	0.74	0.97	0.78	7.1	3.0	46.1	25.0
„	123	160	40	1.2	0.54	0.77	—	4.9	—	40.0	—
III	5	100	50	0.2	—	0.8	—	0.8	—	6.2	—
IV	10	50	—	0.21	0.2	0.54	0.45	1.2	1.4	14.2	19.5
„	62	100	70	0.4	—	0.74	—	1.7	—	15.0	—
„	84	100	60	0.3	0.16	0.88	0.22	1.1	2.3	8.1	66.0
„	86	120	70	1.0	0.2	0.70	0.6	4.5	0.52	41.0	2.7
V	4	100	80	—	—	—	—	—	—	—	—
„	19	180	116	1.7	0.5	0.84	0.5	6.3	3.1	47.6	39.5
„	23	100	90	0.64	0.6	0.96	1.3	2.1	1.4	13.7	7.0
„	39	120	65	0.6	0.32	0.79	0.48	2.4	2.1	19.0	28.0
„	43	—	130	5.0	2.0	—	1.3	—	4.8	—	23.0
„	122	120	70	0.7	0.6	0.66	—	3.3	—	31.0	—
VI	56	120	100	0.45	0.24	0.78	0.79	1.8	0.95	14.0	7.5
„	103	180	180	1.1	0.5	0.81	—	4.3	—	34.0	—
Mean.		**119**	**72**	**1.07**	**0.56**	**0.87**	**0.63**	**3.5**	**1.9**	**24.9**	**20.4**

9. Very Slight Earthquakes.

In Tables XV and XVI, I give the elements of motion of those earthquakes, in which Tokyo was exactly, or very nearly, on the boundary of the area of disturbance ; the average results being as follows :—

Hitotsubashi (23 earthquakes) :

Mean $2a=0.47$ mm, $T_o=0.74$ sec.

Hongo (22 earthquakes) :

Mean $2a=0.35$ mm, $T_o=0.64$ sec.

Central Meteorological Observatory (46 earthquakes) :

Mean $2a=0.44$ mm, $T_o=0.83$ sec.

It will be noticed that the 2a's thus found are nearly identical with the values of the constants j found respectively for the three places of observation. (See § 13.)

The maximum accelerations corresponding to the above mean values of 2a and T_o are as follows :—

For Hitotsubashi,...............$A=17.0$ mm/s^2.

,, Hongo....................... ,, 16.9 ,,

,, Central Met. Observatory. ,, 12.6 ,,

The mean value of the accelerations thus found is

$$A=17.0 \text{ mm/s}^2,*$$

which is to be regarded as the acceleration of the earthquake motion just sufficiently strong to be perceptible to us without instrumental aid, that is to say, the acceleration of the slightest *macro-seismic motion*. (See the *Publications*, No. 10, p. iv.)

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* The results for the Central Meteorological Observatory excepted. See the foot-note to Table XVI.

TABLE XV.—SLIGHTEST EARTHQUAKES.

Hitotsubashi and Hongo.

Hitotsubashi.				Hongo.			
Group.	No.	2a (mm).	T_0 (sec.)	Group.	No.	2a (mm).	T_0 (sec.)
V	19	1.70	0.84	III	17	0.05	0.60
II	29	0.30	—	V	19	0.50	0.50
,,	38	0.35	0.90	II	20	0.16	0.60
VI	48	1.00	0.57	,,	29	0.20	0.70
III	49	0.25	0.60	V	44	0.20	—
II	50	0.25	0.62	II	50	0.15	0.50
VI	56	0.45	0.78	VI	56	0.24	0.79
II	56	0.40	0.70	II	60	0.10	0.23
,,	61	0.32	0.86	,,	61	0.32	0.30
V	71	0.35	0.91	V	43	2.00	1.30
II	76	0.35	0.75	VI	103	0.50	—
IV	92	0.25	0.57	III	124	0.14	0.34
VII	94	0.45	0.83	V	174	1.20	1.13
V	97	0.43	0.73	,,	192	0.20	0.67
IV	82	0.25	0.71	II	194	0.40	—
V	43	5.00*	—	VII	197	0.50	1.16
VI	103	1.10	0.81	V	212	0.14	0.84
III	115	0.10	—	,,	214	0.10	0.56
IV	126	0.25	0.82	VII	215	0.20	1.14
V	131	0.75	0.75	II	216	0.24	0.43
IV	137	0.63	0.79	,,	219	0.10	0.20
VI	138	0.17	0.68	IV	220	0.10	0.25
IV	161	0.13	0.51				
Mean.	......	**0.47**	**0.74**	**Mean.**	......	**0.35**	**0.64**

* Excepted in taking the means.

TABLE XVI.—SLIGHTEST EARTHQUAKES.

Central Meteorological Observatory.

Group.	No.	2a (mm).	T_0 (sec.).	Group.	No.	2a (mm).	T_0 (sec.).
III	17	0.2	1.2	III	115	Small.	—
IV	18	0.2	0.3	,,	118	,,	—
V	19	1.0	1.8	V	122	1.2	0.5
II	20	0.4	—	III	124	0.3	0.5
,,	29	Small.	—	V	131	0.2	0.9
V	44	0.7	1.4	VI	134	0.4	1.4
VI	48	1.6	2.1	IV	137	0.2	1.8
III	49	Small.	—	V	144	0.8	1.5
II	50	Very small.	—	II	152	Small.	—
,,	53	,,	—	IV	161	,,	—
V	54	,,	—	,,	163	Very small.	—
VI	56	0.7	—	V	173	0.2	0.2
II	59	Small.	—	II	188	0.2	0.6
,,	60	,,	—	V	189	0.2	0.6
,,	61	0.4	0.2	,,	192	Small.	—
V	71	0.2	1.5	II	194	0.4	0.5
II	76	0.2	0.5	III	195	Small.	—
IV	79	Small.	—	II	208	0.2	0.5
,,	89	0.2	0.8	V	212	Small.	—
VII	94	Small.	—	,,	214	0.5	0.6
VI	103	0.4	1.2	II	216	0.3	0.5
V	104	0.2	1.0	,,	219	Small.	—
IV	114	0.4	0.4	Mean.*	......	**0.44**	**0.83**

* In deducing the mean values of 2a and T_0, those earthquakes whose 2a was *small* have been excluded. This would cause the value of the 2a to be slightly larger than the true one. As, moreover, the T_0 is for these earthquakes are not given, the mean values of the 2a and T_0 here found have not been taken into account in the deduction of the general mean value of A (page 60).

10. Period of Earthquake Vibration at Hitotsubashi.

To see the dependence, if any, of the period of vibration on the magnitude of earthquakes or on the position of the centres, I have constructed Table XVII which gives, for the 34 earthquakes whose origins and areas of disturbance are definitely known, the following quantities :

T=Average period of vibration ;

d=Distance of earthquake origin from Tokyo ;

r=Mean radius of propagation.

The earthquakes are arranged in order of r.

As will be seen from Table XVII (and also from the results contained in Table XII), there is no relation at all between the T (or T_o) and the distance (d) or the mean radius (r). The conclusion is that the period T at Hitotsubashi is essentially characteristic to the locality itself, and depends little on the distance of the origin or on the magnitude of the earthquake. Such is probably also true of other districts, where the soil is very soft.

TABLE XVII.—TABLE SHOWING THE CONSTANCY OF THE PERIOD OF VIBRATION AT HITOTSUBASHI

Group.	No.	Average period (sec.)	d (km).	Mean r (km).
IV	137	0.77	41	32
III	49	0.74	32	34
IV	161	0.62	35	38
,,	126	0.77	38	44
III	14	0.83	52	51
V	42	0.89	90	57
IV	82	0.74	63	58
II	76	0.76	44	59
IV	10	0.54	49	63
II	59	0.71	53	65
,,	38	0.85	80	76
III	142	0.83	29	82
II	50	0.70	60	84
III	155	0.74	40	87
IV	84	0.78	56	87
,,	86	0.76	52	90
,,	21	0.63	22	92
V	71	0.88	140	100
II	123	0.71	62	105
IV	62	0.85	63	115
II	83	0.84	58	128
V	97	0.71	144	144
VII	94	0.85	280	164
V	131	0.77	190	180
,,	19	0.77	125	185
,,	122	0.78	150	185
,,	23	0.83	160	230
II	65	0.76	69	240
VI	103	0.78	270	265
II	78	0.83	56	265
VI	138	0.75	380	270
,,	56	0.67	390	390
,,	48	0.45	600	600
V	39	0.83	150	—

11 Period of Earthquake Vibration at the Central Meteorological Observatory.

The period of the maximum horizontal vibration T_0 in the 53 earthquakes observed at the Central Meteorological Observatory varied between 0.2 sec. and 1.8 sec., the frequency of the different periods being as follows :—

Number of cases.	Period of hor. motion.		Number of cases.	Period of hor. motion.	
	sec.			sec.	
2	0.2	sec.	0	1.1	
2	0.3	0.30 (mean).	4	1.2	sec.
2	0.4		1	1.3	1.34 (mean).
10	0.5		2	1.4	
6	0.6		3	1.5	
4	0.7		0	1.6	
6	0.8	0.69 (mean).	1	1.7	1.80 (mean).
2	0.9		4	1.8	
4	1.0				

Dividing the 53 cases into four groups, as indicated in the above table, the mean values are found to be respectively 0.30, 0.69, 1.34 and 1.80 sec., these being roughly in the ratios of 1: 2: 4: 6. The periods most frequently occurring are from 0.5 to 1.0 sec.

The period of the maximum vertical vibration, given in 13 cases, was as follows :—

Number of cases.	Period of vert. motion.	Number of cases.	Period of vert. motion.
	sec.		sec.
3	0.3	3	0.6
2	0.4	2	0.7
2	0·5	1	0.8

12. Direction of Earthquake Motion.

The following table gives, for Hitotsubashi and Hongo, the 2a and direction of the maximum horizontal motion in the 15 earthquakes, in which these two elements of motion were distinctly measured ; the distance and direction of the seismic origins from Tokyo being also given for the sake of reference.

Place of observation.	Group. No.		Max. 2a (mm.)	Direction of max. motion.	Distance and direction of earthquake origin from Tokyo.	
Hitotsubashi	II	50	0.25	N—S	60 km	N 54° E.
Hongo	„	28	2.4	N 15° W	60	S 21° W.
„	„	65	1.4	NEN.	69	N 15° E.
„	„	123	0.54	SW	62	N 22° W.
Hitotsubashi	III	142	0.38	E	29	N 18° W.
Hongo	IV	154	7.2	S 48° E.	29	S 15° E.
Hitotsubashi	V	19	1.7	S 70° W	125	N 77° E.
„	„	23	0.64	SE	160	N 78° E.
„	„	42	0.38	E—W	90	S 62° E.
Hongo	„	13	15.0	N 84° E	125	S 85° E.
„	„	23	0.6	S	160	N 78° E.
„	„	43	2.0	W 20° N	107	N 65° E.
„	„	122	0.6	S	150	N 61° E.

From the above table it seems that in the majority of cases, in which the 2a is large, the direction of motion points more or less approximately towards, or from, the origin of disturbance.

13. On the Amplitude of Vibration and the Duration of Earthquake Motion.

AMPLITUDE.

To find the relation, if any, respecting the maximum range of motion in the different earthquakes observed at a given station, let us assume the equation,

$$2a = j \times \frac{r}{d}, \qquad (1)$$

in which j is a constant, r the mean radius (in km) of the area of disturbance, d the distance (in km) between the earthquake origin and a given observing station, and $2a$ the maximum range of motion (in mm) at the latter. This equation may be deduced as follows: Let $2a_0$ be the *mean* range of motion at the boundary of the area of disturbance. If now the earth's crust be supposed to be a homogeneous medium, the amplitude varies inversely with the distance from the earthquake origin; we have therefore

$$\frac{2a}{2a_0} = \frac{r}{d}$$

or $$2a = 2a_0 \times \frac{r}{d}, \qquad (1')$$

Thus j in equation (1) corresponds to $2a_0$ in equation (1′), that is to say, j denotes the motion at a given station which is just large enough to be felt by people without instrumental aid.

DURATION

With respect to the duration of an earthquake at a given station, I assume, as already done in the case of the Miyako earthquake observations,* the relation

$$D = k \times \frac{r^2}{d}, \qquad (2)$$

in which k is a constant, r and d have the same signification as in equation (1), and D is the duration (in sec.) of an earthquake at a given station. This equation is based on the supposition that D is proportional to the magnitude of an earthquake, or the area of disturbance, and inversely proportional to the distance between the origin and the station.

* Omori and Hirata: *Earthquake Measurement at Miyako*, Jorn. Sc Coll., Imp. Univ., Tokyo, Vol. XI.

Tables XVIII to XX give the values of r and d, as well as the elements of motion for the earthquakes of Groups II to VII observed at Hitotsubashi, Hongo and the Central Meteorological Observatory, of which the duration (D) and the range of motion (2a) were accurately measured. Similarly Table XXI, which is given for the sake of comparison, indicates the values of $2a$, D, d and r for the 45 earthquakes observed by the late Professor Sekiya between Sept. 1885 and Aug. 1887 at Hitotsubashi.*

Observing station.	r (km)	d (km)	D (sec.)	$2a$ (mm)	$j=\frac{2a\ d}{r}$	$k=\frac{d\ D}{r_2}$
Hitotsubashi, (Table XVIII)	61	41	66	0.38	0.26	0.73
	86	57	130	0.99	0.66	1.00
	110	71	105	0.70	0.45	0.62
	181	139	128	0.85	0.65	0.54
	348	384	95	0.52	0.52	0.25
	Mean ...	...	...	... ...	**0.51**	... **0.63**
Hitotsubashi, (Table XXI)	62	23	78	0.43	0.16	0.47
	100	56	97	0.78	0.44	0.54
	124	108	105	0.62	0.54	0.74
	228	212	154	0.95	0.88	0.63
	Mean ...	...	...	... ...	**0.51**	... **0.60**
	General Mean ...	...	...	...	**0.51**	... **0.62**
Hongo. (Table XIX)	119	31	115	1.25	0.33	0.25
	99	67	64	0.46	0.31	0.44
	194	129	86	0.59	0.39	0.29
	250	169	142	0.54	0.37	0.58
	312	307	133	0.41	0.40	0.42
	Mean ...	...	...	... ...	**0.36**	... **0.36**
Cent. Met. Observatory, (Table XX)	87	32	67	0.40	0.15	0.28
	87	63	90	0.64	0.46	0.75
	208	138	110	0.52	0.34	0.35
	341	319	123	0.47	0.44	0.34
	Mean ...	...	...	... ...	**0.35**	**0 43**

* The data in Table XXI are taken from Professor Sekiya's paper before referred to; the earthquakes chosen being those for which d and r are definitely known.

To determine the values of the constants j and k, which are to be regarded as *seismic coefficients* for a given locality with regard to the amplitude and the duration, I have divided the earthquakes contained in each of Tables XVIII to XXI arbitrarily to a convenient number of groups and calculated in each case the mean values of the different quantities. These latter and the corresponding values of j and k for Hitotsubashi, Hongo and the Central Meteorological Observatory are given in the above table.

Considering the nature of the question, the agreement of the values of each of the constants for the different places of observation must be regarded as being tolerably satisfactory. In these calculations I have not taken the focal depth into consideration. The result is in general slightly improved if we correct for this latter factor.

From the above it will be seen that the corresponding seismic coefficients for Hongo and the Central Meteorological Observatory are nearly identical to one another while the values for Hitotsubashi are larger than those for the two other places ; the mean values of the constants being as follows.

Hitotsubashi : $j=0.51$, $k=0.62$.

Hongo : $j=0.36$, $k=0.36$.

Cent. Met. Observatory : $j=0.35$, $k=0.43$.

TABLE XVIII.—EARTHQUAKES OBSERVED AT HITOTSUBASHI. (Groups II—VII.)

Group.	No.	r (km)	d (km)	D (s)	$2a$(mm)	T_e (s)	$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	T (s)
IV	21	92	22	180	—	—	—	—	0.63
III	115	25	23	—	0.1	—	—	—	—
,,	142	82	29	70	0.38	0.87	1.4	9.9	0.83
,,	49	34	32	25	0.25	0.6	1.3	13.0	0.74
IV	161	38	35	25	0.13	0.51	0.8	9.9	0.62
,,	126	44	38	60	0.25	0.82	1.0	7.1	0.77
III	155	87	40	100	0.3	0.65	1.4	14.0	0.74
IV	137	32	41	120	0.63	0.79	2.5	20.0	0.77
II	76	59	44	60	0.35	0.75	1.6	14.0	0.76
IV	10	63	49	50	0.21	0.54	1.2	14.2	0.54
,,	92	53	51	30	0.25	0.57	1.4	16.0	—
,,	86	90	52	120	1.0	0.70	4.5	41.0	0.76
Mean		**61**	**41**	**66**	**0.38**				
II	59	65	53	100	0.4	0.7	1.8	16.0	0.71
,,	29	60	55	—	0.3	—	—	—	—
,,	78	65	56	240	2.2	0.97	7.1	46.1	0.83
IV	84	87	56	100	0.3	0.88	1.1	8.1	0.78
II	83	128	58	180	1.8	0.94	6.0	40.0	0.84
,,	50	84	60	30	0.25	0.62	1.3	12.9	0.70
,,	28	155	60	—	2.8	—	—	—	—
Mean		**86**	**57**	**130**	**0.99**				
II	123	105	62	160	1.2	0.77	4.9	40.0	0.71
IV	82	58	63	60	0.25	0.71	1.1	10.0	0.74
,,	62	115	63	100	0.4	0.74	1.7	15.0	0.85
II	65	240	69	150	2.0	0.77	8.2	67.0	0.76
,,	38	76	80	100	0.35	0.9	1.2	8.5	0.85
,,	61	93	89	—	0.32	0.86	1.2	9.0	—
V	42	57	90	60	0.38	0.91	1.3	9.1	0.89
Mean		**110**	**71**	**105**	**0.7**				
V	43	255	107	—	5.0	—	—	—	—
,,	19	185	125	180	1.7	0.84	6.3	47.6	0.77
,,	71	100	140	110	0.35	0.91	1.2	8.0	0.88
,,	97	—	144	50	0.43	0.73	1.9	16.0	0.71
,,	39	—	150	120	0.6	0.79	2.4	19.0	0.83
,,	122	185	150	120	0.7	0.66	3.3	31.0	0.78
,,	23	235	160	100	0.64	0.96	2.1	13.7	0.83
Mean		**181**	**139**	**128**	**0.85**				
VI	103	—	270	180	1.1	0.81	4.3	34.0	0.78
VII	94	164	280	60	0.45	0.83	1.7	13.0	0.85
VI	138	270	380	80	0.17	0.68	0.79	7.3	0.75
,,	56	390	390	120	0.45	0.78	1.8	14.0	0.67
,,	48	680	680	120	1.0	0.57	5.5	60.0	0.45
Mean		**384**	**384**	**95**	**0.52**				

TABLE XIX.—EARTHQUAKES OBSERVED AT HONGO.

Groups II—VII.

Group.	No.	r (km)	d (km)	D (s)	2a(mm)	T_e (s)	V $\left(\frac{mm}{s}\right)$	A $\left(\frac{mm}{s^2}\right)$	T (s)
IV	171	160	0	80	0.7	0.25	9.0	221.0	{ 1.2 / 0.75
„	177	120	23	80	0.3	0.26	3.6	87.6	{ 1.6 / 0.79
III	124	24	26	20	0.14	0.34	1.3	2.4	—
IV	154	360	29	480	7.2	1.3	17.4	84.1	1.07
„	220	47	36	15	0.1	0.25	1.3	31.5	0.44
„	10	63	49	—	0.2	0.45	1.4	19.5	0.44
II	60	62	51	16	0.1	0.23	1 4	37.3	0.23
Mean		**119**	**31**	**115**	**1.25**				
IV	86	90	52	70	0.2	0.6	0.52	2.7	{ 2.1 / 1.3
II	29	60	55	40	0.2	0.7	0.9	8.1	—
„	78	65	56	140	0.74	0.78	3.0	25.0	0.70
IV	84	87	56	60	0.16	0.22	2.3	66.0	2.0
II	179	90	58	25	0.26	0.49	1.7	21.4	2.6
„	194	70	60	120	0.4	—	—	—	1.2
„	50	84	60	35	0.15	0.5	0.94	12.0	—
„	28	155	60	100	2.4	0.8	9.4	74.0	0.53
„	219	79	60	30	0.1	0.20	1.6	49.3	—
„	123	105	62	40	0.54	—	—	—	—
IV	62	115	63	70	—	—	—	—	—
II	65	240	69	110	1.4	0.71	6.2	55.0	0.68
„	216	73	73	30	0.24	—	—	—	0.43
VII	184	120	74	60	0.1	—	—	—	0.58
III	17	89	80	65	0.05	0.6	0.3	2.7	{ 1.4 / 0.5
II	20	96	85	70	0.16	0.6	0.8	8.8	—
„	61	93	89	30	0.32	0.3	3.4	72.0	{ 0.37 / 0.19
„	208	70	100	50	—	—	—	—	—
Mean		**99**	**67**	**64**	**0.46**				

TABLE XIX.—(*Continued*).

Group.	No.	r (km)	d (km)	D (s)	2a(mm)	T_o (s)	$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	T (s)
V	212	—	107	30	0.14	0.84	0.5	3.9	0.88
,,	43	255	107	130	2.0	1.3	4.8	23.0	0.67
,,	172	225	115	100	0.8	0.69	—	—	0.88
,,	13	380	125	270	15.0	—	—	—	{1.3, 0.57}
,,	19	185	125	116	0.5	0.5	3.1	39.5	{0.48, 0.93}
,,	46	225	130	115	0.5	0.57	2.8	31.0	0.65
,,	192	150	137	60	0.2	0.67	0.9	8.8	—
,,	44	135	140	—	0.2	—	—	—	—
,,	39	—	150	65	0.32	0.48	2.1	28.0	0.60
,,	122	185	150	70	0 6	—	—	—	0.52
Mean.		**194**	**129**	**86**	**0.59**				
V	23	235	160	90	0.6	1.3	1.4	7.0	0.69
,,	174	300	160	200	1.2	1.13	3.3	18.5	1.18
VII	215	190	160	90	0.2	1.14	0.6	3.0	1.32
V	214	200	170	90	0.1	0.56	0.6	8.8	0.55
,,	176	315	195	240	0.6	1.43	1.3	5.8	{1.2, 2.3}
Mean.		**250**	**169**	**142**	**0.54**				
VII	197	234	260	120	0.5	1.16	1.4	7.3	1.19
VI	103	—	270	180	0.5	—	—	—	—
,,	56	390	390	100	0.24	0.79	0.95	7.5	0.74
Mean.		**312**	**307**	**133**	**0.41**				

TABLE XX.—EARTHQUAKES OBSERVED AT THE CENTRAL METEOROLOGICAL OBSERVATORY.

Groups II–VII.

Group.	No.	r (km).	d (km).	D (s).	2a (mm).	T_o (s).
IV	171	160	0	90	4 1	0.6
,,	114	23	21	25	0.4	0.4
,,	89	24	21	20	0.2	0.8
III	156	80	21	120	Small.	—
IV	21	92	22	45	0.2	0.5
,,	177	120	23	90	1.5	0.7
III	115	25	23	30	Small.	—
,,	124	24	26	90	0.3	0.5
IV	154	360	29	372	—	—
III	70	305	29	—	Small.	—
,,	142	82	29	12	0.5	0.3
,,	49	34	32	10	Small.	—
II	152	45	34	10	,,	—
IV	161	38	35	15	,,	—
,,	220	47	36	10	,,	—
,,	18	40	37	180	0.2	0.3
III	195	60	37	30	Small.	—
,,	155	87	40	120	0.2	—
II	143	200	38	120	1.1	1.0
IV	137	32	41	120	0.2	1.8
,,	163	41	41	30	Small.	—
II	53	52	44	30	,,	—
,,	76	59	44	10	0.2	0.5
III	158	80	44	30	Small.	—
IV	10	63	49	10	0.4	0.7
Mean.		**87**	**32**	**67**	**0.4**	

TABLE XX.—(*Continued.*)

Group.	No.	r (km).	d (km).	D (s).	2a (mm).	T_e (s).
II	60	62	51	30	Small.	—
IV	86	90	52	100	0.3	0.8
II	69	60	52	480	5.6	0.8
,,	59	65	53	88	Small.	—
III	125	92	53	270	1.9	0.4
II	188	48	55	50	0.2	0.6
,,	29	60	55	10	Small	—
,,	78	65	56	270	—	—
IV	84	87	56	20	0 4	1.2
,,	79	55	57	60	Small.	—
II	179	90	58	50	0.3	0.5
,,	83	128	58	180	1.5	1.3
,,	194	70	60	60	0.4	0.5
,,	50	84	60	12	Small.	—
,,	28	155	60	120	2.5	1.5
,,	219	79	60	35	Small.	—
,,	123	105	62	60	0.3	0.8
III	118	54	68	30	Small.	—
II	65	240	69	120	1.2	0.7
,,	216	73	73	40	0.3	0.5
VII	184	120	74	—	0.3	0.9
III	17	89	80	12	0.2	1.2
II	20	96	85	120	—	—
,,	61	93	89	25	0.4	0.2
V	42	57	90	10	Small.	—
,,	54	62	95	50	,,	—
II	208	70	100	25	0.2	0.5
Mean.		87	63	90	0.64	
V	212	—	107	50	Small.	—
,,	43	255	107	228	—	—

TABLE XX.—(*Continued.*)

Group.	No.	*r* (km).	*d* (km).	D (s).	2a (mm).	T_0 (s).
V	172	225	115	75	0.5	0.5
IV	182	160	120	—	0.8	1.0
V	13	380	125	360	—	—
,,	19	185	125	120	1.0	1.8
,,	144	—	126	120	0.8	1.5
,,	104	200	130	70	0.2	1.0
,,	46	225	130	45	—	—
,,	55	—	130	15	Small.	—
,,	192	150	137	30	,,	—
,,	71	100	140	120	0.2	1.5
,,	44	135	140	109	0.7	1.4
,,	97	—	144	180	—	—
,,	39	—	150	60	0.4	1.8
,,	122	185	150	120	1.2	0.5
,,	23	235	160	90	1.3	1.2
,,	174	300	160	240	—	—
VII	215	190	160	60	—	—
V	173	—	162	20	0.2	0.2
,,	214	200	170	90	0.5	0.6
Mean.		**208**	**138**	**110**	**0.52**	
V	131	—	190	150	0.2	0.9
,,	176	315	195	120	1.2	0.7
VII	197	234	260	120	—	—
V	189	—	260	90	0.2	0.6
VI	103	—	270	180	0.4	1.2
VII	94	164	280	60	Small.	—
VI	56	390	390	90	—	—
,,	134	—	430	240	0.4	1.4
,,	48	600	600	60	—	—
Mean.		**341**	**319**	**123**	**0.47**	

TABLE XXI.—EARTHQUAKES OBSERVED AT HITOTSUBASHI.*

Sept. 1885-Aug. 1887.

Date.		Time of occurrence.	Max. hor. 2a (mm).	D (s).	d (km).	γ (km).
1886.	VI. 14	6. 25. 19 p.m.	0.6	70	0	56
„	IX. 12	8. 43. 22 p.m.	0.8	50	0	105
„	XII 26	5. 48. 5 p.m.	0.8	51	0	105
1885.	X 15	8. 18. 43 p.m.	1.0	148	24	53
„	XI. 16	1. 53. 36 p.m.	Small.	30	24	35
1886.	VI. 11	1. 45. 44 p.m.	0.4	75	24	56
„	III 26	6. 6. 0 p.m.	0.1	65	27	39
1887.	IV. 27	9. 30. 38 p.m.	—	140	27	53
1885.	XII. 3	6. 1. 42 a.m.	0.2	60	32	47
1886.	„ 29	11. 5. 43 a.m.	0.5	60	35	69
„	X. 4	2. 35. 25 p.m.	0.3	85	40	64
„	„ 25	10. 11. 18 p.m.	0.4	100	40	64
	Mean.		**0.43**	**78**	**23**	**62**
1885.	XII. 28	10. 6. 30 p.m.	3.5	210	47	158
1886.	II 24	7. 34. 0 a.m.	0.5	105	47	118
,	V 5	——	0.2	54	47	52
„	„ 18	8. 12. 51 p.m.	0.5	135	47	137
„	VIII. 3	2. 11. 40 a.m.	Small.	20	48	48
„	XI. 2	8. 21. 46 p.m.	0.2	100	48	56
„	XII. 8	11. 58. 16 a.m.	0.3	122	48	56
1887.	V. 17	4. 19. 44 p.m.	0.2	20	48	64
1886.	„ 8	10. 14. 0 p.m.	2.1	144	52	137
„	X. 22	3. 49. 14 a.m.	0.5	65	55	113
1887.	IV. 16	3. 35. 0 a.m.	0.4	112	56	60
1885.	XII. 19	6. 28. 0 p.m.	2.8	106	60	258
1886.	IX. 16	1. 2. 57 p.m.	0.1	50	64	80

* Compiled from the late Prof. S. Sekiya's paper: *Earthquake Measurement, etc.*, Jour. Sc. Coll. Imp. Univ. Tokio, II.

TABLE XXI.—(*Continued*).

Date.			Time of occurrence.	Max. hor. 2a (mm).	D (s).	d (km).	γ (km).
1887.	VII.	2	3. 16. 24 p.m.	0.6	61	73	89
1885.	IX.	2	8. 36. 0 p.m.	0.3	150	74	87
1887.	VI.	22	7. 42. 39 a.m.	0.3	98	77	85
Mean.				**0.78**	**97**	**56**	**100**
1886.	V.	30	8. 38. 18 p.m.	0.4	90	92	92
1885.	X.	1	1. 9. 0 p.m.	1.0	120	95	145
„	„	18	0. 15. 0 p.m.	0.3	60	95	98
1886.	I.	4	8. 31. 30 p.m.	0.4	54	95	98
„	„	5	4. 26. 42 p.m.	0.8	75	106	118
„	III.	13	6. 25. 0 p.m.	0.7	120	110	118
1887.	VI.	20	8. 38. 30 a.m.	0.4	95	113	161
1885.	X.	11	5. 28. 18 a.m.	1.1	243	114	134
1886.	III.	2	5. 3. 49 a.m.	0.6	130	118	126
„	VI.	3	3. 6. 37 p.m.	0.4	91	122	122
1885.	X.	24	5. 12. 18 p.m.	0.7	75	130	150
Mean.				**0.62**	**105**	**108**	**124**
1887.	VIII.	15	0. 59. 15 a.m.	—	185	169	193
1885.	IX.	26	0. 30. 0 p.m.	—	215	177	235
„	X.	26	10. 41. 11 p.m.	2.2	200	180	224
1886.	IV.	4	1. 0. 0 a.m.	0.4	130	216	235
„	XII.	11	10. 16. 25 p.m.	0.4	76	242	193
1887.	II.	2	2. 8. 14 p.m.	0.8	118	287	290
Mean.				**0.95**	**154**	**212**	**228**

Macro-seismic Measurement in Tokyo. III.

By

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1. Introduction.

The present paper, which is to be regarded as a supplement to the preceding, contains lists of the strong earthquakes observed in Tokyo, with some notes on the range of motion and the period of vibration of earthquakes at the Central Meteorological Observatory.

2. Strong Earthquakes observed at Hitotsubashi and Hongo.

The following is a list† of the stronger earthquakes observed at Hitotsubashi and Hongo since 1884.

Eqke of Oct. 17th 1884 : 4.21.54 a.m.* *Hitotsubashi.*

This was a severe earthquake which caused some slight damage in Tokyo. The origin was, when judged from the isoseismal curves situated at about 200km to S 60° E of Tokyo, namely, at about *lat.* 35°N and *long.* 141°½ E. The motion was already large in the preliminary tremor, the 2a being 3.9 mm in the EW and 1.6 mm in the NS component. Then there followed suddenly a large vibration, whose first displacement was 13 mm in the direction S 60° E, and whose

† Not including a few earthquakes whose measurement was not satisfactory.

* An account of this earthquake by the late Professor Sekiya is to given in the Japanese Transactions of the Seis. Soc. Japan, No. 3.

second displacement was 42 mm in the direction N 60° W ; the period being 2.0 s. The subsequent motion was not registered as the EW pointer got soon after out of the record-receiver. (The vertical motion was not measured.)

Eqke of Jan. 15th 1887 : 6.52.0 p.m.,* *Hitotsubashi*.†

This was also one of the severest earthquakes in recent years, which shook Tokyo ; the centre of the epi-focal region being at about 55 km to the S 60° W of the observing place.

The preliminary tremor lasted about 9 sec., the max. 2a being 4.7 mm in the EW and 3.0 mm in the NS component. The very first well defined displacement after the preliminary tremor was the following :—

26mm toward W, 7 mm toward S ; resultant 2a=27 mm, direction S 75° W. The motion remained nearly constant during the next 25.4 sec. ; the max. 2a was 38 mm in each horizontal component (the resultant 2a=54 mm), while the average period was 0.97 sec. Thereafter large pendulum oscillations of the *steady masses* of the seismograph set in, and the subsequent earthquake motion was not measured satisfactorily.

Eqke of Sept. 5th 1887 : 3.23. 23 p.m. *Hongo*.

This was an extensive earthquake whose submarine origin, inferred from the isoseismal lines, was about 125 km to S 85° E of Tokyo, at about *lat.* 35° 33′ ond *long.* 141° 10′ E.

In the preliminary tremor, which lasted 15 sec., the max. EW. NS and vertical movements were respectively 3.2 mm. 2.2 mm and

* An account of this earthquake by the late Professor Sekiya is given in the Jour. Sc. Coll., Imp. Univ., Tokyo. Vol. I, and also in Trans. Seis. Soc. Japan, Vol. XI.

† Recorded by a *strong motion seismograph*.

0.3 mm. Then there followed suddenly the following well defined maximum vibration :—

$2a=15.0$ mm, $T_0=3{,}0$s, direction N 84° E. The subsequent motion was much smaller. The maximum vertical motion was 0.5 mm.

Eqke of Feb. 2nd 1888 : 1.15. 15 p.m. *Hongo.*

The max. 2a was 2.0 mm in the EW and 1.0 mm in the NS component, the period being 1.4 sec. The average period of the principal waves was 1.1 sec.

Eqke of April 29th 1888 : 10.0.33 a.m. *Hongo.*

The max. 2a in the preliminary tremor was 0.5 mm in the EW and 0.3 mm in the NS component.

max. $2a=2.0$ mm, $T_0=1.0$ s. (EW compt) ;
,, $=1.1$ mm, $T_0=1.2$ s. (NS compt).

Eqke of Feb. 18th 1889 ; 6.27 45 a.m. *Hongo.*

During the preliminary tremor, the max. 2a was 0.8 mm in the EW and 0.7 mm in the NS component. In the principal portion, the maximum movements were as follows :—

Principal undulation $\begin{cases} \text{max. } 2a=4.1 \text{ mm, } T_0=\text{——— (EW),} \\ \text{,, } =2.8 \text{ mm, } T_0=1.60 \text{ s (NS).} \end{cases}$

Ripple. $\begin{cases} \text{max. } 2a=2.4 \text{ mm, } T_0=\text{——— (EW).} \\ \text{,, } =1.65 \text{ mm, } T_0=0.6 \text{ s (NS).} \end{cases}$

Eqke of Dec. 24th 1891 : 5.33. 14 a.m. *Hongo.*

The following vibration (period=1.5 s) took place immediately after the preliminary tremor :—

1st displacement $\begin{cases} \text{1 mm toward W, 2.7 mm toward N ;} \\ \text{resultant } 2a=2.9 \text{ mm, direction N 20° W} \end{cases}$

2nd displacement $\begin{cases} \text{2.1 mm toward E, 8. 3 mm toward S ;} \\ \text{resultant } 2a=8.6 \text{ mm, direction S 14° E,} \end{cases}$

Eqke of June 30th 1892 : 7. a.m *Hongo.*

During the preliminary tremor, the max. 2a was 0.9 mm in the EW and 1.1 mm in the NS component.

The preliminary tremor was followed by the follwing prominent maximum motion :—

1st displacement $\begin{cases}\text{13 mm toward E, 6 mm taward S;}\\ \text{resultant 2a=14.3 mm, direction S 65° E.}\end{cases}$

2nd displacement $\begin{cases}\text{27 mm toward W, 18 mm toward N;}\\ \text{resultant 2a=32.4 mm, direction N 57° W.}\end{cases}$

Eqke of June 20th 1894 : 2.4. 10 p.m. *Hongo.**

This was the most violent that has shaken Tokyo since the well known great catastrophe of the 2nd year of Ansei (1855). In the lower parts of the city, many brick buildings received severe damage, and chimneys in particular were mostly thrown down. Some *dozo* (godowns) had their plastered mud walls very much cracked and shaken down, small cracks were formed in the ground, etc. The number of casualties in the three Prefectures of Tokyo, Kanagawa, and Saitama were 26 persons killed and 171 wounded.

Max. horizontal 2a=73 mm, direction S70° W, period=1.8 sec. Max. vertical 2a=10 mm.

Eqke of June 20th 1894 ; 4.22. 44 p.m. *Hongo.*

The preliminary tremor during which the max. 2a was 0.2 mm in the EW and 0.3 mm in the NS component, was suddenly followed by a prominent single maximum movement in each horizontal component :—

2a=3.3 mm (EW), 2a=3.8 mm (NS), period=0.78 sec.

Same eqke. Hitotsubashi.†

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* See the *Publications*, No. 4.

† Observed in a pit 30′ deep.

The preliminary tremor whose max. 2a was 1.0 mm in the EW and 0.9 mm in the NS component was succeeded by the following well defined maximum vibration :—

2a=9 mm (EW), 2a=6.5 mm (NS), period=1.0 s.

Eqke of Aug. 29th 1894 : 7.55. 18 p.m. *Hitotsubashi.**
Max. 2a=3.6 mm, period=1.3 s (EW),
„ =3.5 mm, „ =1.04 s (NS).

Eqke of Nov. 30th 1894 : 8.30, 57 p.m. *Hitotsubashi.**
Max. horizontal 2a=10.5 mm, period=1.0 s.

Eqke of Jan. 23rd 1895 : 2.12. 30 p.m. *Hongo.*

The preliminary tremor lasted 7.2 sec. The max. movements were as follows :—

2a=1.4 mm, period=0.49 s (EW),
„ 1.0 mm, „ 0.54 s (NS),
„ 0.3 mm, „ 0.60 s (vertical).

Eqke of Feb. 23rd, 1896 ; 7.41. 47 p.m. *Hongo.*

An earthquake at a distance, whose preliminary tremor lasted 40 sec.

Max. 2a=10 mm, period=1.9 sec.

Eqke of March 6th 1896 : 11.51.31. p.m. *Hongo.*
Max. 2a=2.2 mm, period=0.43 s (EW),
„ 3.2 mm, „ 0.43 s (NS).

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* Observed in a pit 30′ deep.

Same eqke. Hitotsubashi.

Max.2a=4.5 mm, period=0.88 s (EW);

,, 3.6 mm, ,, 0.87 s (NS).

Eqke of April 24th 1896 ; 10.49.56 a.m. *Hitotsubashi.*

Max. 2a=3.8 mm, (EW) ;

,, =4.4 mm, period=0.79 s (NS).

Eqke of May 6th 1897 ; 6.46.35 a.m. *Hitotsubashi.*

Max. 2a=4.5 mm, period=1.4 s (EW) ;

,, =3.9 mm, ,, =1.7 s (NS).

Eqke of Dec. 26th 1897 : 4.41.25 p.m. *Hitotsubashi,*

Max. 2a=1.7 mm, period=1.2 s (EW);

,, =2.8 mm, ,, =1.6 s (ES).

Eqke of April 23rd 1898 : 8.37.0 a.m. *Hitotsubashi.*

Max. 2a=8.2 mm, period=2.3 s (EW).

The results are summarized in the following table.

TABLE I.—STRONG EARTHQUAKES OBSERVED AT HITOTSUBASHI AND HONGO.

Date.	Time of occurrence.	Duration of preliminary tremor (sec.)	Max. horizontal 2a (mm).	Period of max. hor. 2a (sec.)	Direction of max. hor. motion, etc.
			Hitotsubashi.		
Oct. 17, 1884.	4.21.54 a.m.	—	42.0	2.0	N 60° W.
Jan. 15, 1887.	6.52.0 p.m.	About 9.	54.0	0.97	Initial motion of the principal portion = 27 mm, direction S 75° W.
June 20, 1894.	4.22.44 „	6.	9.0 (EW) 6.5 (NS)	1.00	
Aug. 29, „	7.55.18 „	—	3.6 (EW) 3.5 (NS)	1.30 (EW) 1.00 (NS)	
Nov. 30, „	8.30.57 „	—	10.5	1.00	
Mar. 6, 1896.	11.51.31 „	—	4.5 (EW) 3.6 (NS)	0.88 (EW) 0.97 (NS)	
April 24, „	10.49.56 a.m.	—	3.8 (EW) 4.4 (NS)	— 0.79 (NS)	
May 6, 1897.	6.46.35 „	—	4.5 (EW) 3.9 (NS)	1.4 (EW) 1.7 (NS)	
Feb. 26, „	4.41.25 p.m.	—	1.7 (EW) 2.8 (NS)	1.2 (EW) 1.6 (NS)	
April 23, 1898.	8.37.0 a.m.	—	8.2 (EW)	2.3 (EW)	
			Hongo.		
Sept. 5, 1887.	3.23.23 p.m.	15	15.0	3.0	N 84° E.
Feb. 2, 1888.	1.15.15 „	—	2.0 (EW) 1.0 (NS)	1.4	(Average period = 1.1 sec.)
April 29, „	10.0.33 a.m.	—	2.0 (EW) 1.1 (NS)	1.0 (EW) 1.2 (NS)	
Feb. 18, 1889.	6.27.45 „	10.5	4.1 (EW) 2.8 (NS)	— 1.6 (NS)	Ripples:— 2a = 2.4 (EW), T = — 2a = 1.7 (NS), T = 0.6 s.
June 30, 1892.	7. „	—	32.4	—	N 57° W.
Dec. 24, 1891.	5.33.14 „	—	8.6	1.5	S 14° E.
June 20, 1894.	2.4.10 p.m.	—	73.0	1.8	S 70° W.
June 20, „	4.22.44 „	5.9	3.3 (EW) 3.8 (NS)	0.78	
Jan. 23, 1895.	2.12.30 „	7.2	1.4 (EW) 1.8 (NS) 0.3 (V)	0.49 (EW) 0.54 (NS) 0.60 (V)	
Feb. 23, 1896.	7.41.47 „	40.0	10.0 (EW)	1.9	
Mar. 6, „	11.51.31 „	—	2.2 (EW) 3.2 (NS)	0.43 (EW) 0.43 (NS)	

*Hitotsubashi observations.** Of the ten earthquakes, whose horizontal 2a varied between about 3 and 54 mm, six had periods equal or very nearly equal to 1 second, while the periods of the other four varied between 1.4 sec. and 2.3 sec. The mean period of the first six is 0.97 sec. or very nearly 1 sec., which may be taken as the period most likely to occur in *strong* or *weak*† earthquakes. The remaining four earthquakes give a mean period of 1.8 sec. These two values of the period may be denoted by the letters t_1 and t_2 respectively. It will be observed that the large displacements such as 10.5 mm and 54 mm belonged to the t_2 class vibrations. The inference is that destructive horizontal earthquake movements at Hitotsubashi will probably have a period not much different from 1 sec.

Hongo observations. Of the eleven *strong* and *weak* earthquakes recorded at Hongo, whose max. horizontal motion varied between about 2 mm and 73 mm, the periods were as follows :—

in six cases, the max. 2a varied between 2.5 mm and 73 mm, while the period varied between 1.1 sec. and 1.9 sec., giving a mean value of 1.6 sec. ;

in four cases, the max. 2a varied between 2.0 mm and 3.8 mm, while the period varied between 0.43 sec. and 0.78 sec., giving a mean value of 0.58 sec.

in the remaining one case, the max. 2a was 15 mm, while the period was 3.0 sec.

Excepting the last case which evidently belongs to waves of slow periods, we thus find the mean value of the period most frequently occuring is 1.6 sec., and that next frequently occurring is 0.58

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* The pit observations excluded.

† The intensity of ordinary or non-destinctive earthquakes is distinguished as *slight*, *weak* or *strong*. See the *Publications*, No. 10. p. iii.

sec. These two values may, for the sake of convenience, be denoted by the symbols t_1' and t_2' respectively. It will be noted that the max. 2a's belonging to the t_2' class were, in the present instance, all less than about 4 mm, while large 2a's, such as 10 mm and 73 mm belonged to the t_1' class. Hence I believe that large strong and destructive (horizontal) earthquake movements at Hongo, or generally in the higher part of Tokyo, will have a period belonging to the t_1' class, that is to say, not much different from 1.6 sec.

If the two periods denoted by t_1' and t_2' for Hongo correspond to the two denoted by t_1 and t_2 for Hitotsubashi, we see that the period t_2' is shorter than t_2 in the ratio of about 6:10, while the two slower periods t_1 and t_1' do not much differ from one another. This can probably be explained on the ground that slow period vibrations have large wave lengths and consequently their amplitudes do not much differ in adjacent districts of different formations. In fact, it is clear from the horizontal pendulum records that, with slow undulations of periods greater than 6 or 7 sec., there is no difference at all between Hongo and Hitotsubashi.

3. Strong Earthquakes observed at the Central Meteorological Observatory.

The following table gives the elements of motion of the 56 stronger earthquakes observed between Jan. 1885 and Dec. 1897 at the Central Meteorological Observatory, in which the maximum horizontal motion was greater than 1.5 mm.*

* I have omitted several cases of large earthquake motion, in which the period was above 2 sec., as such slow movements can not be satisfactorily recorded by Gray-Milne seismographs.

TABLE II.—LIST OF EARTHQUAKES (MAX. 2A $>$1.5 MM) OBSERVED AT THE CENTRAL METEOROLOGICAL OBSERVATORY.

Date.	Time of occurrence.	Max. hor. 2a (mm).	T_0 (sec).	$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	Duration.	Max. vert. 2a (mm).
						m s	
1885. III. 20	1. 1. 13. pm.	2.6	1.3	6.2	30.0	2.40	0.5
„ XII. 19	6. 26. 40. pm.	1.8	1.0	5.7	36.1	2.43	0.4
„ „ 28	10. 6. 30. pm.	3.3	1.8	5.6	19.0	3.40	Slight.
1886. V. 8	10. 14. 00. pm.	2.8	0.4	22.0	346.0	1.40	0.5
„ „ 16	9. 3. 00. am.	1.7	0.7	7.6	68.0	3.00	0.9
1887. V. 29	0. 50. 57. am.	1.8	0.8	7.1	55.5	3.25	—
„ VII 22	8. 27. 0. pm.	1.7	0.9	5.9	41.4	3.34	—
„ XII. 16	8. 28. 21. am.	2.5	1.5	5.2	21.9	2.00	0.3
1888. IV. 29	10. 0. 33. am.	5.6	0.8	22.0	173.0	8.00	—
„ VI. 3	7. 53. 8. am.	1.5	1.3	3.6	17.3	3.00	—
„ XI. 3	8. 13. 33. am.	1.9	0.4	14.9	233.0	4.30	—
1889. III. 28	1. 20. 10. am.	4.1	0.6	21.5	230.0	1.30	0.6
„ IV. 3	4. 27. 21. pm.	1.5	0.7	6.7	59.9	1.30	0.2
„ VIII. 5	7. 34. 56. am.	1.7	1.1	4.9	28.2	4.20	—
1891. IV. 21	10. 49. 7. am.	1.9	1.1	5.4	31.0	3.00	Slight.
„ XII. 24	5. 33. 14. am.	16.2	1.9	26.8	88.6	3.40	2.0
1892. I. 17	11. 35. 12. pm.	2.4	0.8	9.4	73.9	2.40	0.2
„ „ 31	10. 23. 16. am.	1.6	0.8	6.3	49.3	1.40	0.2
„ VI. 3	7. 9. 57. am.	28.4	2.0	44.6	140.0	7.30	4.4
„ IX. 13	11. 29. 42. pm.	2.6	0.4	20.4	320.4	2.00	0.3
„ XII. 29	10. 43. 57. am.	1.5	1.5	3.1	13.1	2.40	—
1893. I. 8	5. 40. 27. pm.	3.5	0.3	36.6	777.1	2.30	0.9
„ III. 6	8. 52. 18. am.	1.7	0.6	8.9	93.0	3.20	0.2
„ VIII. 20	0. 28. 27. pm.	3.6	0.5	22.6	283.7	4.00	1.0
1894. I. 10	6. 46. 23. pm.	1.5	1.0	4.7	29.6	3.15	—
„ II. 20	8. 29. 3. am.	5.1	1.6	10.0	39.3	4.20	Slight.
„ „ 27	0. 53. 0. pm.	2.4	1.4	5.4	24.2	2.21	„

TABLE II.—(*Continued*).

Date.	Time of occurrence.	Max. hor. 2a (mm).	T_0 (sec).	$V\left(\frac{mm}{s}\right)$	$A\left(\frac{mm}{s^2}\right)$	Duration.	Max. vert. 2a (mm).
1894. VI. 20	2. 4. 10. pm.	76.0	1.3	183.0	888.0	m s 4.48	18.0
„ „ 25	5. 15. 36. pm.	4.8	0.8	18.8	148.0	1.45	0.7
„ VII. 17	11. 1. 21. pm.	1.7	0.7	10.8	68.5	3.27	0.6
„ VIII. 29	7. 55. 18. pm.	1.8	1.8	3.1	11.0	6.00	—
„ XI. 30	8. 30. 57. pm.	5.0	0.6	26.2	274.2	2.27	1.7
„ XII. 31	10. 7. 42. am.	1.8	1.6	3.5	13.9	3.5	—
1895. I. 18	10. 48. 24. pm.	41.0	0.9	143.0	997.2	4.4	11.0
„ „ 23	2. 12. 30. pm.	2.4	0.7	10.8	96.5	2.10	0.6
„ IX. 24	1. 48. 10. am.	1.7	0.6	8.9	93.0	1.8	Slight.
„ X. 11	3. 11. 53. pm.	6.1	0.2	95.8	3004.0	0.55	1.3
1896. I. 10	11. 24. 29. am.	1.7	1.3	4.1	19.9	4.22	—
„ „ 22	4. 43. 40. am.	2.3	0.5	14.5	181.6	2.50	—
„ II. 23	7. 41. 47. pm.	3.7	1.0	11.6	73.0	3.55	—
„ III. 6	11. 51. 31. pm.	4.3	0.6	22.5	236.0	2.00	0.4
„ IV. 11	10. 59. 49. pm.	1.5	0.3	15.7	329.0	2.52	0.2
„ „ 24	10. 49. 56. am.	2.5	0.7	11.2	100.7	2.6	0.2
„ V. 17	3. 39. 59. am.	1.8	1.2	4.7	24.7	2.20	0.2
„ VII. 29	5. 43. 36. pm.	3.2	0.8	12.6	98.7	2.16	0.2
„ VIII. 1	11. 49. 4. am.	2.2	0.8	8.6	67.9	2.7	0.3
„ „ 20	6. 5. 37. pm.	2.9	0.3	30.4	636.0	0.50	0.2
„ XII. 17	1. 17. 25. am.	1.9	0.2	29.8	938.0	0.47	0.4
1897. I. 17	0. 49. 28. am.	4.0	0.7	17.9	161.1	3.32	0.3
„ II. 7	4. 38. 33. pm.	1.7	0.7	7.6	68.5	5.47	—
„ II. 20	5. 49. 37. am.	22.8	1.5	47.4	200.0	5.13	2.6
„ „ 28	1. 14. 58. am.	3.1	1.4	7.0	31.2	2.20	0.2
„ V. 23	9. 23. 00. pm.	1.7	1.7	3.1	11.6	2.40	Slight.
„ VII. 22	6. 31. 44. pm.	7.3	1.3	17.6	85.3	4.34	0.3
„ VIII. 16	4. 53. 33. pm.	3.0	1.0	9.4	59.2	3.00	—
„ X. 2	9. 45. 19. pm.	1.8	1.0	5.7	35.5	3.25	0.2

The period distribution of the 56 cases tabulated above is as follows :—

TABLE III.

Period (sec.).	Number of cases.	Period (sec.).	Number of cases
0.2	3	1.1	2
0.3	3	1.2	1
0.4	4	1.3	5
0.5	1	1.4	1
0.6	5	1.5	4
0.7	7	1.6	2
0.8	7	1.7	1
0.9	2	1.8	2
1.0	5	1.9	1
		2.0	1

From the above table it will be seen that the period of the maximum horizontal motion most frequently occurring is from 0.6 sec. to 0.8 sec. ; the 2a's belonging to this group varied between 1.6 mm and 5.6 mm, giving a mean value of 2.8 mm, as follows :—

5.6, 5.0, 4.8, 4.3, 4.1, 4.0, 3.2, 2.5, 2.4, 2.4, 2.2, 1.8, 1.7, 1.7, 1.7, 1.7, 1.6, 1.5 mm.

The 2a's of the vibrations with periods of 0.2 sec. to 0.5 sec., varied between 1.5 mm and 6.1 mm, giving a mean value of 2.9 mm, as follows :—

6.1, 3.5, 2.9, 2.8, 2.6, 2.3, 1.9 1.9, 1.5 mm.

Thus it will be seen that the mean values of the vibrations with periods of 0.2 sec. to 0.5 sec. and of 0.6 sec. to 0.8 sec. are respectively 2.8 mm and 2.9 mm, the maximum 2a's being in the two cases 6.1 mm and 5.6 mm. Hence it is extremely probable that great destructive movements would have periods longer than those here

considered. In fact there are, among the 56 earthquakes, six in which 2a was very great, as follows :—

TABLE IV.

	Max. hor. 2a (mm).	T_0 (sec.).
	76.0	1.3
	41.0	0.9
	28.4	2.0
	22.8	1.5
	16.2	1.9
	7.3	1.3
Mean.	32.0	1.5

The mean value of the period deduced from the cases of greatest movements (mean $2a=32$ mm) is thus found to be 1.5 sec., which may be regarded to be not much different from the period of strong earthquake motion at the ground of the Central Meteorological Observatory.

The 2a's corresponding to periods other than those above considered varied between 1.5 mm and 5.1 mm, as follows :—

TABLE V.

Max. hor. 2a (mm).	T_0 (sec.).	Max. hor. 2a (mm).	T_0 (sec.).
5.1	1.6	1.8	1.6
3.7	1.0	1.8	1.2
3.6	0.5	1.8	1.0
3.3	1.8	1.8	1.0
3.1	1.4	1.7	0.9
3.0	1.0	1.7	1.1
2.6	1.3	1.7	1.3
2.5	1.5	1.7	1.7
2.4	1.4	1.5	1.3
1.9	1.1	1.5	1.0
1.8	1.8	1.5	1.5
	Mean.................	2.3	1.2

The mean value of the 2a's for the 22 earthquakes tabulated above is 2.3 mm, the corresponding mean period being 1.2 sec. For the convenience of reference, I collect below the results thus far obtained.

TABLE VI.

Number of cases.	Period ;	mean value.	2a ;	mean value.
	sec. sec.	sec.	mm. mm.	mm.
9	0.2—0.5 ;	0.33	1.5— 6.1 ;	2.9
19	0.6—0.8 ;	0.71	1.5— 5.6 ;	2.8
22	0.9—1.8 ;	1.20	1.5— 5.1 ;	2.3
6	0.9—2.0 ;	1.50	7.3—76.0 ;	32.0

4. Seismographical Observations at the Central Meteorological Observatory, 1885-1897.

The following remarks are based on the earthquake measurement reported by the Central Meteorological Observatory.

Period.

The Gray-Milne seismograph at the Central Meteorological Observatory, which was first used in Jan. 1885, has recorded during the next 13 years 1404 earthquakes of which 433 gave seismograms large enough to enable us to measure one or more elements of motion distinctly. The results, however, relating to a number of earthquakes, in which the period of the maximum vibration (T_o) was long, must be regarded in general as unsatisfactory, because ordinary Gray-Milne seismographs do not record accurately vibrations of periods much above 2 sec. Confining, therefore, our attention to those cases in which the period of the maximum vibration was less than 2 sec., we find 362 earthquakes ; the period distribution being as follows :—

TABLE VII.

Number of cases.	T_o (sec.).	Number of cases.	T_o (sec.).
4	0.1	11	1.1
21	0.2	20	1.2
25	0.3	13	1.3
22	0.4	12	1.4
34	0.5	12	1.5
29	0.6	5	1.6
35	0.7	4	1.7
46	0.8	10	1.8
21	0.9	3	1.9
27	1.0	8	2.0

The mean value of T_0 deduced from all these 362 cases is 0.84 sec.

From the above table it will be seen that the values of T_0 most frequently occurring is between 0.5 sec. and 0.8 sec., there being 144 cases corresponding to these periods, which are equivalent to about 40% of the whole number. The periods occurring next frequently are those between 0.2 sec. and 0.4 sec. and between 0.9 sec. and 1.5 sec. On the whole, the number of the cases corresponding to the periods between 0.2 sec. and 1.5 sec. amount to 328, which is equivalent to about 91% of the whole. These results are summarized in the following table :—

TABLE VIII.

Period.	Number of cases.	% amount.
sec. sec. 0.1—0.4	72	20
0.5—0.8	144	40
0.9—1.2	79	22
1.3—1.6	42	12
1.7—2.0	25	7

Maximum Horizontal Motion.

Among the 433 earthquakes instrumentally observed at the Central Meteorological Observatory between 1885 and 1897, there are 366 cases in which the maximum horizontal motion 2a was measured ; the cases of the vibrations whose periods were greater than 2 sec. being as before excluded. In 8 cases, the 2a was great, being respectively 5.6 mm ; 6.1 mm ; 16.2 mm ; 7.3 mm ; 22.8 mm ; 28.4 mm ; 41.0 mm ; 76.0 mm. In the remaining 357 cases, the 2a's varied between 0.1 mm and 5.1 mm ; the number of cases corresponding to the different values of 2a being as follows.—

TABLE IX.

Number of cases.	2a (mm).	Number of cases.	2a (mm).
74	0.2	2	2.6
56	0.3	0	2.7
52	0.4	1	2.8
34	0.5	1	2.9
23	0.6	1	3.0
20	0.7	1	3.1
14	0.8	1	3.2
6	0.9	0	3.3
7	1.0	1	3.4
5	1.1	1	3.5
7	1.2	1	3.6
6	1.3	1	3.7
3	1.4	0	3.8
5	1.5	0	3.9
1	1.6	1	4.0
9	1.7	1	4.1
6	1.8	1	4.2
3	1.9	1	4.3
1	2.0	0	4.4
0	2.1	0	4.5
2	2.2	0	4.6
1	2.3	0	4.7
3	2.4	1	4.8
2	2.5	0	4.9
		1	5.0

The above relative frequency of the different 2a's are more shortly given in the following table.—

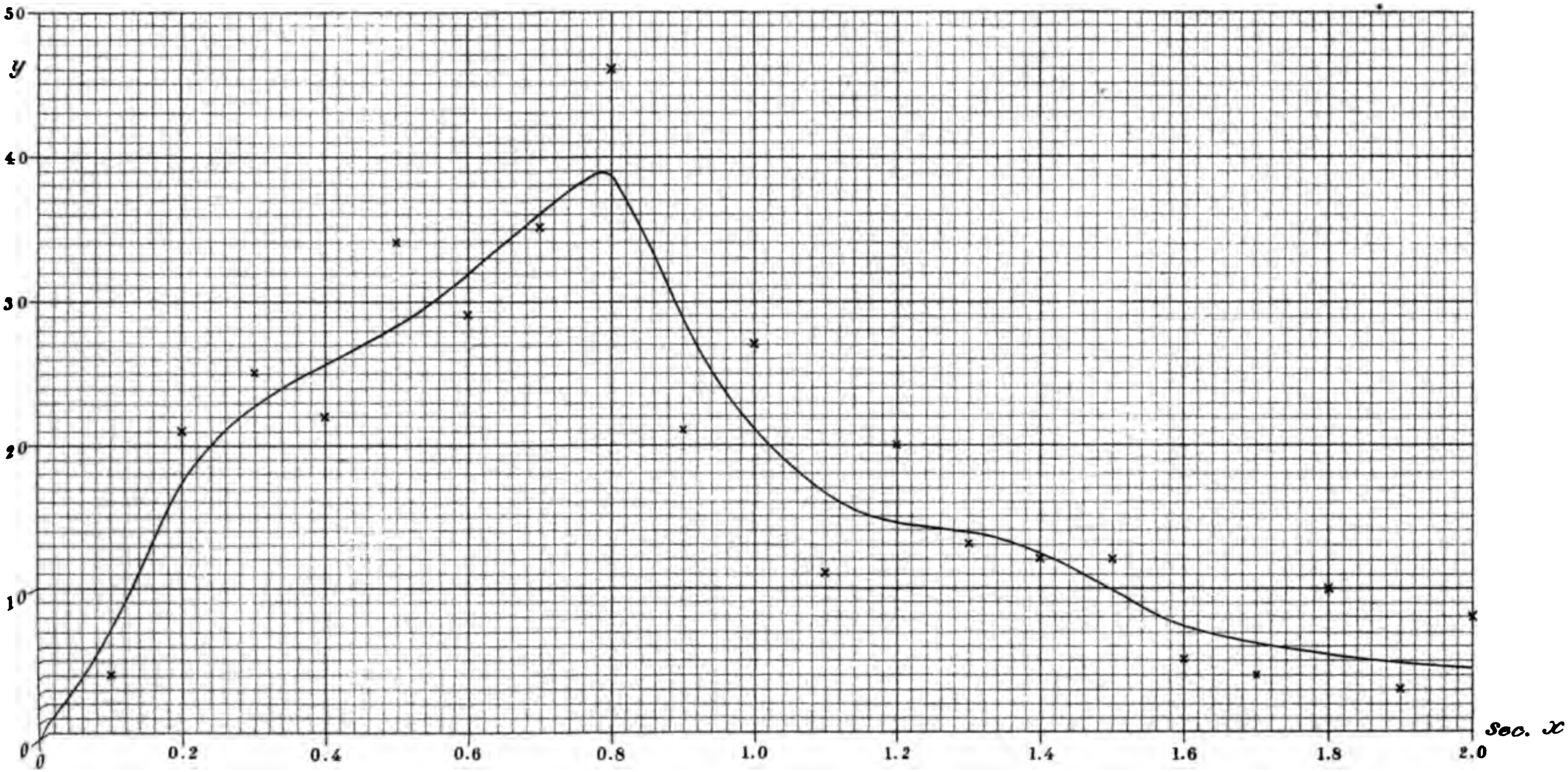
TABLE X.

Max. hor. 2a (mm).	Number of cases.	% amount.
mm. mm. 0.2—0.5	216	59.1
0.6—1.0	70	19.2
1.1—1.5	26	7.1
1.6—2.0	20	5.5
2.1—2.5	8	2 2
2.6—3.0	5	1.4
3.1—3.5	4	1.1
3.6—4.0	3	0.5
4.1—4.5	3	0.8
4.6—5.0	2	0.5
5.1—5.5	1	0.3
5.6—6.0	1	0.3
6.1—6.5	1	0.3

As will be seen from the above table, the great majority fall between 0.2 mm and 0.5 mm and between 0.6 mm and 1.0 mm, the number of cases corresponding to these two groups being 216 and 70, which are respectively 59.1% and 19.2% of the whole.

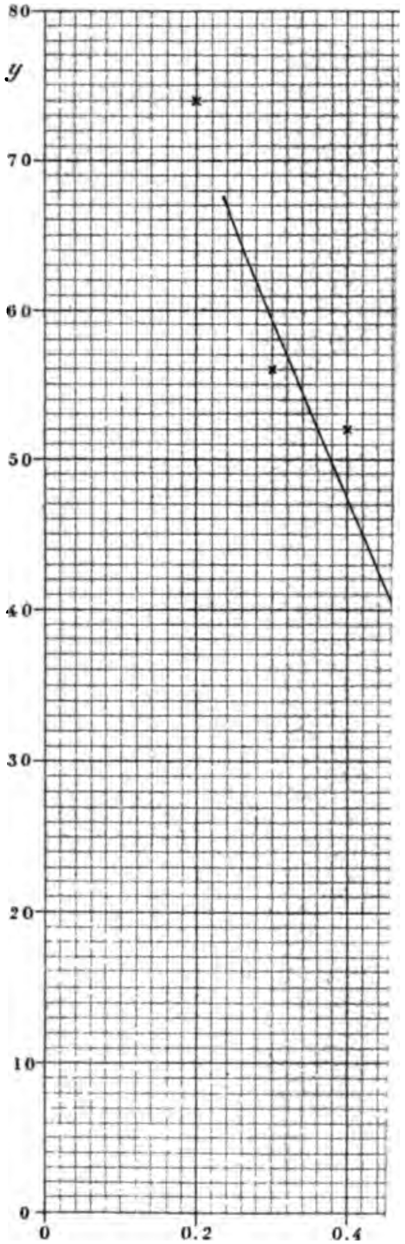
Pl. III and Pl. IV illustrate graphically the results contained in Tables VII and IX respectively.

Distribution of the periods of maximum horizontal motion in the 362 earthquakes observed at the Central Meteorological Observatory.



x = Period of maximum horizontal motion (in sec.)

y = Number of earthquakes, whose period of maximum horizontal motion was x.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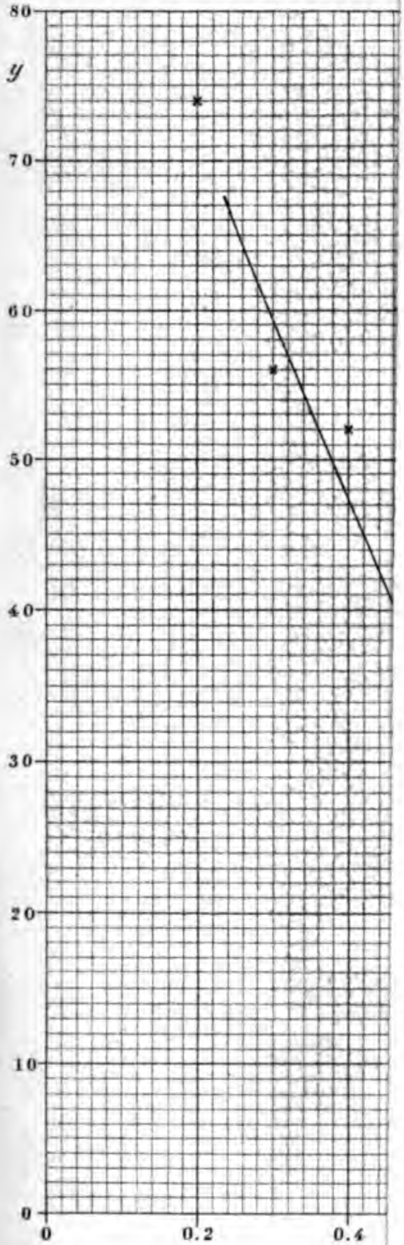
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明治三十五年九月十五日印刷
明治三十五年九月十八日發行

震災豫防調査會

印刷者　齋藤章達
東京市日本橋區兜町二番地

印刷所　東京印刷株式會社
東京市日本橋區兜町二番地

PUBLICATIONS

OF THE

Earthquake Investigation Committee

IN

FOREIGN LANGUAGES.

NO. 12.

TŌKYO, 1903.

CONTENTS.

PRINTED BY THE SANSHUSHA, LIMITED.

A Horizontal Pendulum Tromometer.

By

F. Omori, *Rigakushi, Rigakuhakushi,*

Member of the Imperial Earthquake Investigation Committee.

With Plates I-VI.

The *tromometer*, which is intended to register only very small horizontal movements of the ground and whose mechanical details are given in Pls. I to III, is similar in essential constructive principles to the horizontal pendulum apparatus of 10 to 20 times magnification in use since some years.*

The strong cast iron stand A (figs. 1, 2, 3, and 4), from whose top the heavy mass B is suspended bifilarly, is 120 cm in height and about 50 kg in weight, and is furnished with three levelling screws, being fixed to a stone foundation plate by means of two bolts. For facilitating the setting up of the stand, one of the holes, through which the bolts are passed, is made oblong. (Fig. 3.)

The pendulum bob B is a brass cylinder 16 cm in height and 20 cm in diameter, filled with lead, which is pivoted to a strong frame by means of two screws fitting into two small conical holes at the centres of its upper and lower ends. The frame consists of a vertical rectangle B′ of iron bars, attached at its middle to a horizontal circle B″, also of iron; the latter being furnished with a pair of steel hooks pivoted at the end of its diameter normal to the plane of B′. The cylinder B weighs $42\frac{1}{2}$ kg and its frame 7 kg, the two together amounting to $49\frac{1}{2}$ kg.

The pendulum strut is a short iron tube C, $1\frac{1}{2}$ cm in diameter and of such a length that the distance between the centre of the heavy bob B and the point of support is 20 cm. The strut is furnished with a well

* See the *Publications*, No. 5, and also the Jour. Sc. Coll. Imp. Univ., Tokyo, Vol. XI.

polished conical steel point of about 80° pivoted in a steel socket of about 120° fixed to the lower part of the cast iron stand A. The conical point, which is screwed to the strut, can, when damaged, be replaced by its duplicate; each instrument being furnished with a pair of such points.

The two steel wires, D, about 1 mm in thickness, whose lower ends are attached to the two hooks already mentioned, are suspended from a square screw E, which passes normally through a closely fitting hole in a steel triangular knife F (Fig. 5, Pl. III). The edge of the latter has all been cut away except two small portions with which the prism rests in a V-slot on the inclined hypothenuse face of an isosceles right-angled iron prism G, soldered to a large square screw H. The latter passes through two closely fitting stirrups I′, attached to a thick brass plate I; the azimuthal position of the heavy bob being adjusted by an appropriate movement of the screw H by means of two nuts H′. For adjusting the period of vibration of the horizontal pendulum, the plate I is, in its turn, made to move forwards and backwards on the basal plate J by means of a screw J′. Finally the two screws fixed in the stirrup J″, through which the plate I passes, secure the latter to the plate J.

The right-angled prism G is so perforated as to allow the free passage through it of the screw E. Rectangular cuttings K and L are also for the same purpose made in the two plates I and J. The latter plate is fixed to the top of the cast iron stand A with such an inclination that the plane of the suspension wires is at right angles to the knife edge. The vertical distance between the point of suspension and that of support of the pendulum is 112 cm.

The magnifying arrangement. (Figs. 1, 2, 2′, 4, 6 and 6′.) For magnifying the earthquake motion, the horizontal pendulum is furnished with a light trianglar pointer of aluminium M, carrying at the end a small U-shaped brass frame M′. Between the two limbs of the latter is pivoted a highly polished steel axis M″, 2 mm in diameter and 3 cm in length, which can rotate very easily. The horizontal distance between

the axis M'' and the centre of the heavy cylinder B is 1 m, or five times that between the latter and the point of support. As the centre of the bob B is the *steady point* with respect to a displacement normal to the pendulum plane, the earthquake motion would be registered 6 times magnified, if a writing index be attached to the axis M''. Instead of this, there is a second magnifier, consisting of a small steel axis N, about 2 mm in diameter and $4\frac{1}{2}$ cm in height, to which a light lever N' N'' is attached. The longer arm N' of the lever consists of a thin bamboo piece, while the shorter forked arm N'' is of brass. The axis N, pivoted between two small conical steel sockets fixed in an inverted brass stirrup O, is adjustable along the horizontal rod P of the same metal. The latter is fixed in proper azimuth and height by means of a screw P' to a stout iron cylinder Q rising from a cast iron truncated cone Q', which is furnished with three levelling screws and rests on the ground.

Between the two limbs of the shorter arm N of the magnifying pointer there fits exactly the steel axis N'' at the end of the aluminium prolongation N. On the other hand, a small U-shaped elastic frame of brass at the end of the bamboo arm carries an exceedingly light hinged writing index made of a thin triangular piece, about 5 mgm in weight, cut from a watch spring. The point of the index rests on the record-receiving smoked smooth paper wrapped round a light wooden drum R. The effective lengths of the two arms of the pointer, or the distances NM'' and NN,'' are respectively 15 mm and 30 cm, the motion being thus magnified altogether $20 \times 6 = 120$ times.

The wooden drum R, which is of the same construction as in the older apparatus, makes one revolution in about 30 minutes.

Pressure at the point of support. Let p denote the pressure at the point of support of the pendulum, and f the aggregate tension of the two suspension wires D. We have then the relation :—

$$p = W \tan\alpha, \qquad f = \frac{W}{\cos\alpha};$$

where W denotes the total weight of the heavy bob, and α is the angle between the plane of the two wires D and the vertical plane, or more

exactly the axis of the pendulum. In our case, α is about 10°, while W is approximately 50 kg. We have, therefore,

$$f = \frac{50}{\cos 10^\circ} = 51 \text{ kg},$$

$$p = 50 \times \tan 10^\circ = 9 \text{ kg}.$$

Thus it will be seen that the two wires practically bear the total weight of the heavy bob, while the pressure at the point of support is small and less than $\frac{1}{5}$th of W; this amount of p being equal to what would be produced if α be about 45° and W about 10 kg, as in the horizontal pendulum apparatus of portable form.* Hence the heavy bob exercises, notwithstanding its great weight, a comparatively slight effect on flattening the point of support. Owing to the shortness of the distance between the latter and the *steady point*, it is not possible in the present method of setting up to raise the period of the horizontal pendulum much above 35 seconds. It would be a marked improvement if the cast iron stand A be mounted, as in my long-period pendulum apparatus, on a solid stone column about 2 m high and the socket receiving the point of support be attached at the base. By such a means, the period of oscillation would be raised to some $1\frac{1}{2}$ minutes, while the pressure p is also lessened in an inverse proportion to the height between the points of suspension and of support.

Sensibility of the apparatus. The instrument is highly sensitive to tremors, pulsatory oscillations, and comparatively quick period earthquake vibrations. When, however, the movements of the ground are very slow, say, of period greater than 30 seconds, the record is not much larger than those given by a 15-times magnification apparatus, the reason being that the independent multiplication-pointer N (figs. 1, 2, etc.) exercises, in such cases, a considerable friction at the end of the aluminium frame M. This defect may be remedied to some extent by increasing, say to twice the amount, the weight of the heavy bob, which

* The *Publications*, No. 5, pp. 6–8.

may be done without much danger of flattening the point of suspension. On the whole, the present instrument is, in its capacity as a *tromometer** superior to the others which I have so far constructed.

Suggestions for increasing the sensibility. For the use in a standard seismological observatory, we may increase the weight of the heavy mass to 150 or 200 kg, and the distance between the end of the aluminium frame and the steady point to 2 m; the length of the strut remaining the same as before. If the multiplication ratio of the independent magnifying pointer be made 30, the total multiplication would be 330 times.

RECORDS.

The observation with the tromometer described above has been made since June 1902 in the "Earthquake-proof House" at Hongo (Tokyo). Recently similar instruments were set up in two other stations in Tokyo, namely, the Seismological Observatory at Hitotsubashi and the Central Meteorological Observatory.

In Pls. IV to VI, a few Hongo diagrams given by the tromometer of 120 times magnification are compared with the corresponding ones given by 10 or 15 times magnification horizontal pendulums. The movements recorded will be found to be, in each case, practically proportional to the multiplication ratios of the pointers of the different instruments.

Fig. 7 (Pl. IV) gives the earlier portion of the earthquake of Oct. 13th, 1902, at 1h 19m 35s p.m., which originated off the north-eastern coast of Honshiu (Main Island) and was registered as *unfelt earthquake* at several meteorological observatories by means of ordinary Gray-Milne seismographs.

Fig. 8 (Pl. IV) gives the earlier portion of the earthquake of July 28th, 1902, at 11h 7m 38s p.m., which was felt *weakly* along the south-eastern coast of Hokkaido and at Aomori, and *slightly* in the north-eastern part of Honshiu.

* In case of a moderate local earthquake, or of a large distant earthquake, the registered motion is already too great, and the pointer gets out of the record-receiver.

Fig. 9 (Pl. V) gives the *preliminary tremor* of the Turkestan earthquake of Aug. 22nd, 1902, at 0h 9m 42s p.m. At about 13½m from the commencement of the earthquake, which marks the beginning of the *principal portion*, the motion reached a range of 15mm. This was too large for the tromometer, whose pointer was, in consequence, thrown out of the record-receiver.

Fig. 10 (Pl. VI) gives portions of the diagrams for Oct. 7th-8th, 1602 On account of the great multiplication ratio, the tromometer gives large records of the *pulsatory oscillations*, or slow period small vibrations of the ground, whose origin is not seismic. There exist also almost always very slight quick movements of the ground, which may be called *micro-tremors*. These latter have an average period of about 0.3 second, the motion reaching some times a range of 0.013mm.

第一圖

Fig. 1.

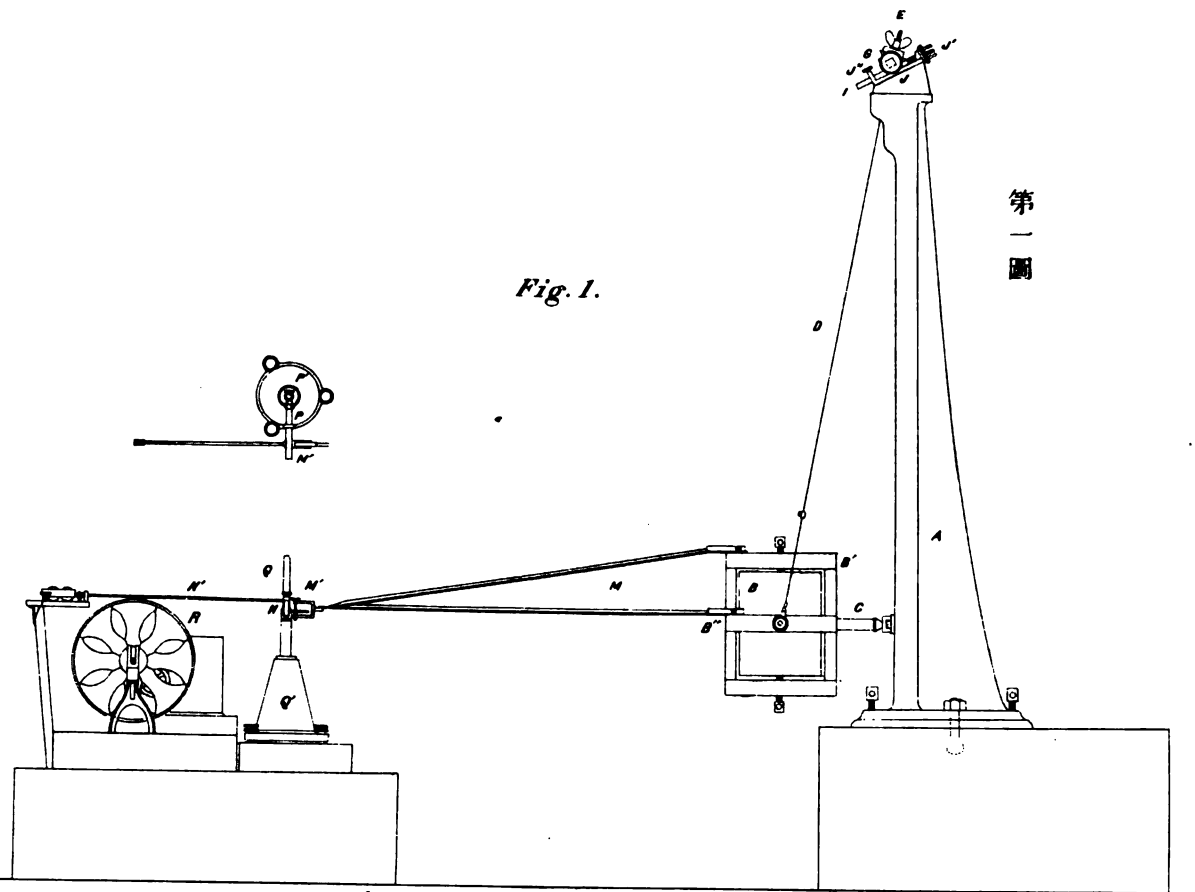
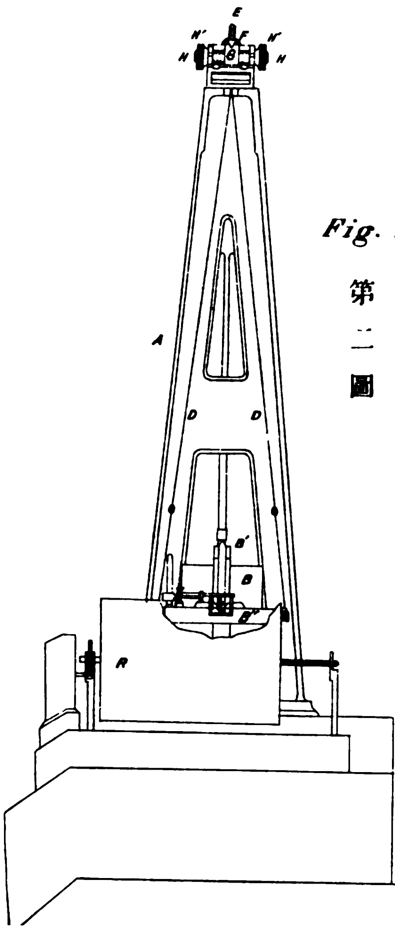


Fig. 2.

第二圖



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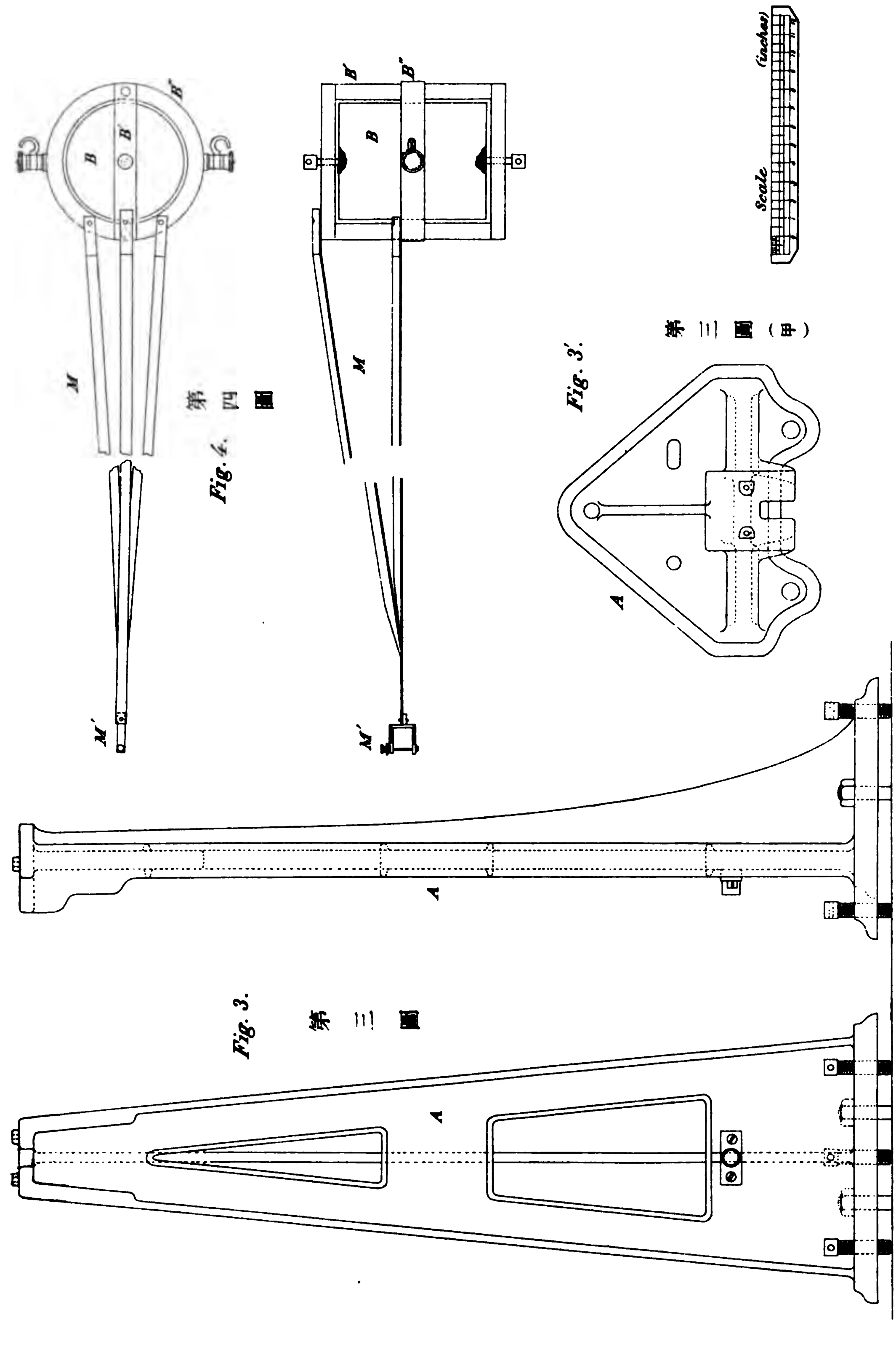
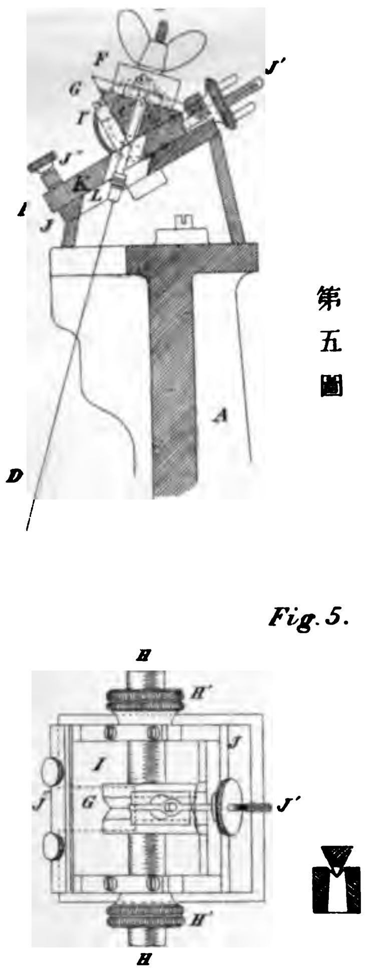


Fig. 4.
第四圖
B
B′
M
M′
M
Fig. 3′.
第三圖(甲)
A
Scale (inches)
Fig. 3.
第三圖
A
A



第五圖

Fig. 5.

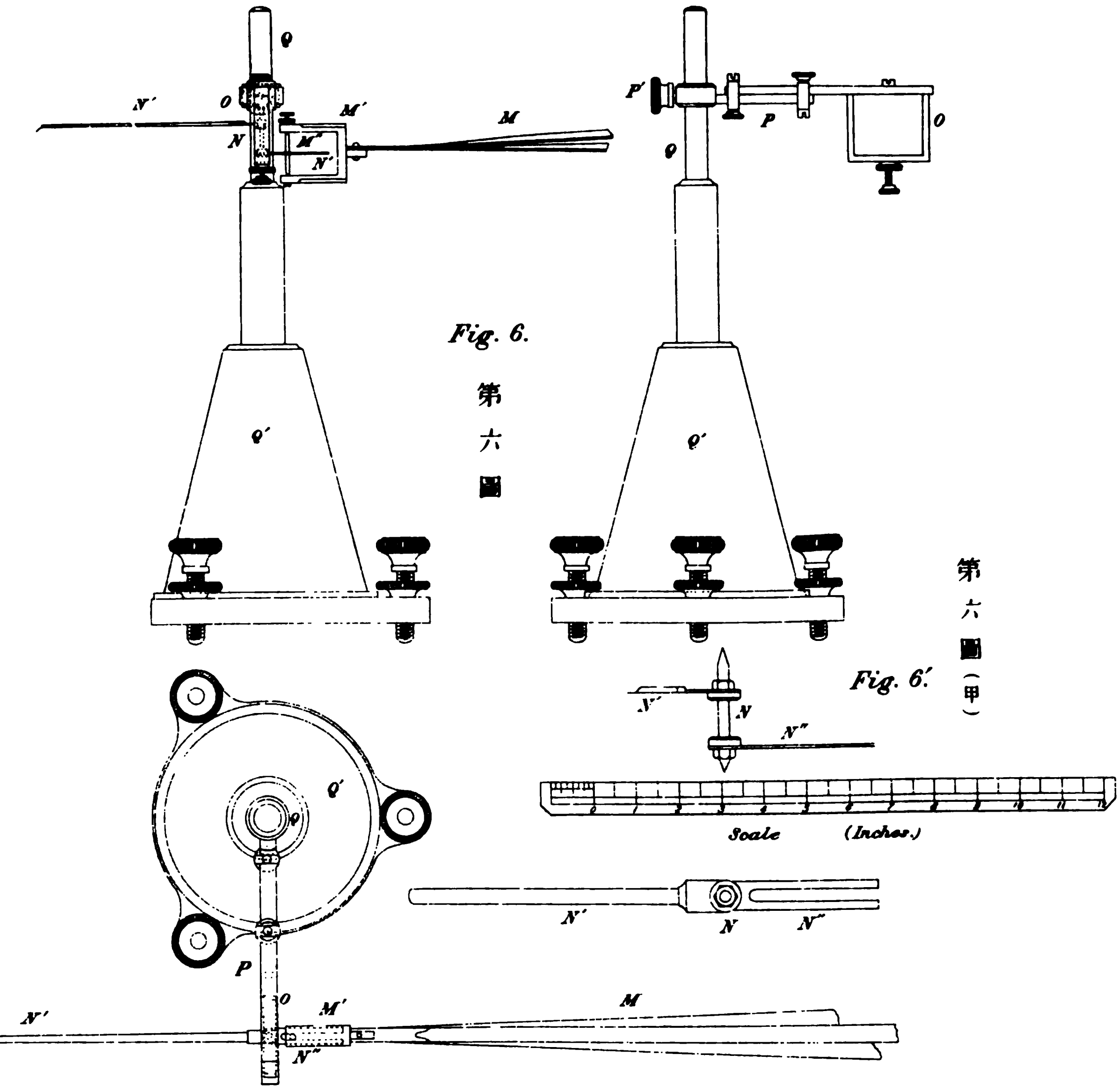


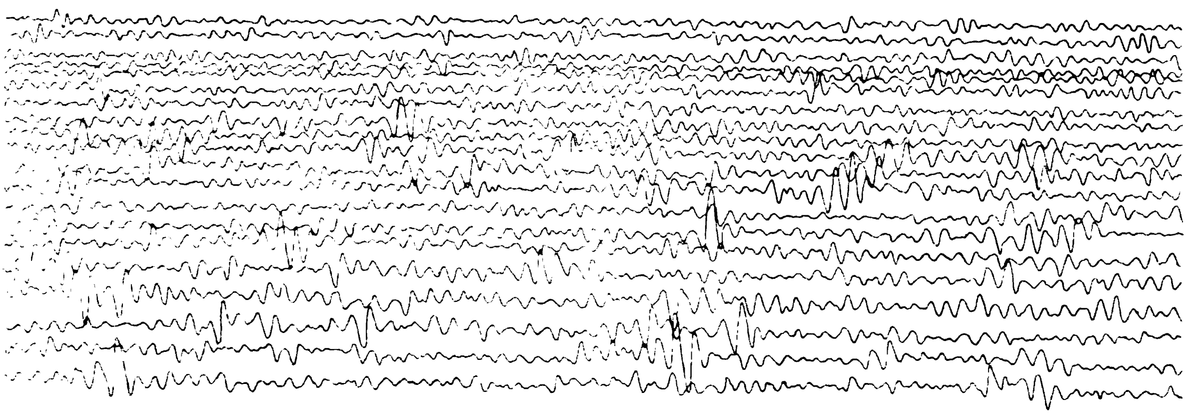
Fig. 6. 第六圖

Fig. 6'. 第六圖(甲)

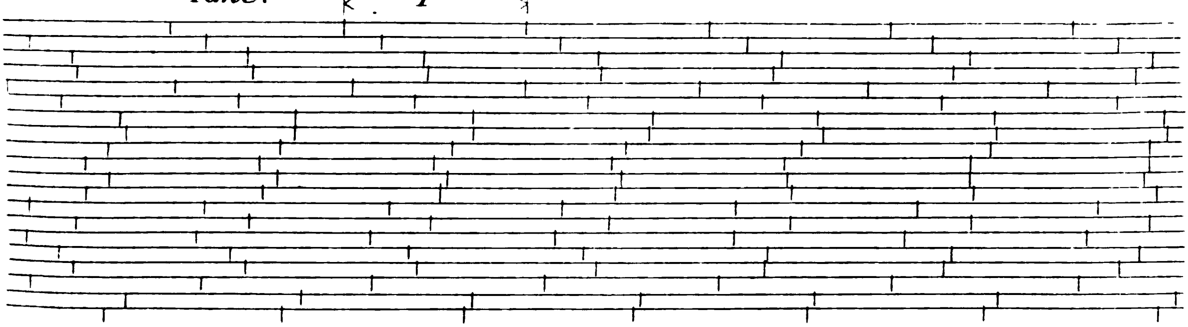
Fig. 10. PULSATORY OSCILLATIONS ON OCT. 7–8, 1902.

(PART OF THE *EW* COMPONENT DIAGRAMS).

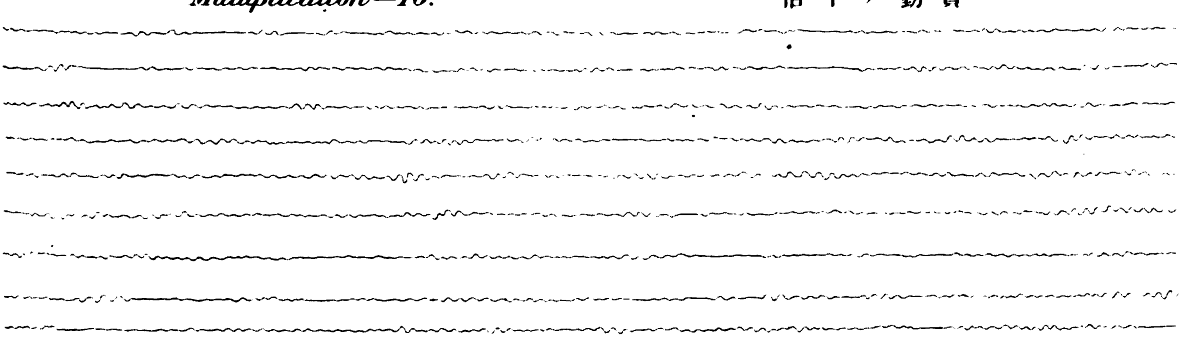
Multiplication = 120. 實動ノ百二十倍



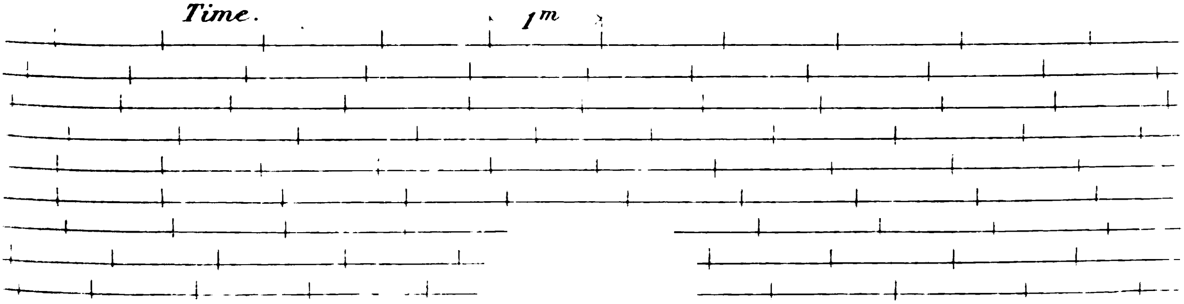
Time. 1^m



Multiplication = 10. 實動ノ十倍



Time. 1^m



LIST OF PLATES.

[*A Horizontal pendulum tromometer ; Multiplication=120.*]

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Pl. II. *Fig. 3.* and *Fig. 3'.* The elevations and plan of the cast iron stand.

Fig. 4. The heavy bob of the pendulum and its aluminium pointer.

Pl. III. *Fig. 5.* The mechanism at the top of the cast iron stand for suspending the pendulum.

Fig. 6. and *Fig. 6.'* The magnifying pointer and the pointer-holder.

[*Diagrams obtained at Hongo, Tokyo ; EW Component.*]

Pl. IV. *Fig. 7.* The earthquake of Oct. 13th, 1902 ; 1h 19m 35s p.m.

(*a*) Record from the tromometer.

(*b*) „ „ a horizontal pendulum apparatus ; multiplication=10.

Fig. 8. The earthquake of July 8th, 1902 ; 11h 7m 38s p.m.

(*a*) Record from the tromometer.

(*b*) „ „ a horizontal pendulum apparatus ; multiplication=15.

Pl. V. *Fig. 9.* The preliminary tremor of the Turkestan earthquake of Aug. 22nd, 1902 ; 0h 9m 42s p.m.

(*a*) Record from the tromometer.

(*b*) „ „ a horizontal pendulum apparatus ; multiplication=10.

Pl. VI. *Fig. 10.* Pulsatory oscillations on Oct. 7th-8th, 1902. (Parts of the EW component diagrams.)

(*a*) Record from the tromometer.

(*b*) „ „ a horizontal pendulum apparatus ; multiplication=10.

In Figs. 7 to 10, the time marks correspond to successive minutes.

Publications of the Earthquake Investigation Committee in Foreign Languages 12 8-27, 1903

On the Overturning and Sliding of Columns.

By

F. Omori, *Rigakushi, Rigakuhakushi,*

Member of the Imperial Earthquake Investigation Committee.

With Plates VIII-XI.

1. *Introduction.* The present note is to be regarded as a supplement to my paper, "Seismic experiments on the overturning and fracturing of columns by horizontally applied motion," (the *Publications*, No. 4), and treats of the overturning and sliding of columns caused by the earthquake motion.

A *column* is to be understood as a body of any form resting simply on the ground or on a support fixed to the latter; the earthquake motion being assumed to be horizontal.

OVERTURNING OF COLUMNS.

2. It is very difficult to discuss generally the phenomena of the overturning of columns. The problem is, however, materially simplified by making certain suppositions as to the relative magnitudes of the dimensions of the columns and the range of the earthquake motion,* and by classifying the former into *large* and *small* ones, as follows:—

(*a*) Large columns, or those whose dimensions, (that is to say the height and the thickness), are sufficiently large in comparison to the earthquake motion;

(*b*) Small columns, or those whose dimensions are not very much larger than the earthquake motion.

3. *The earthquake motion.* I give here some of the results of the macro-seismic measurements made in Japan.

(*a*) In the great Mino-Owari earthquake of Oct. 28th, 1891, the maximum horizontal motion at Nagoya was about 233mm, the period being probably about 1.3 sec. (See my "Note on the Mino-Owari earthquake," the *Publications*, No. 4.)

* The *range* of motion is equivalent to the *double amplitude*.

(*b*) In the great Tokyo earthquake of June 20th, 1894, the strong motion seismograph in the Seismological Institute (Hongo, Tokyo) gave the following results :—

Maximum horizontal motion = 73mm,

Period of max. hor. motion = 1.8sec.,*

Maximum vertical motion = 10mm.

(See Sekiya and Omori's paper "The diagram of the Tokyo earthquake, etc.," the *Publications*, No. 4.)

(*c*) As an example of the measurement of ordinary small earthquakes, I quote here the results obtained by the late Professor S. Sekiya.† During the two years, Sept. 1885 to Aug. 1887, he measured in Tokyo 119 earthquakes with Ewing's seismographs. Of these, 95 measured at Hitotsubashi gave the following average results :—

Maximum horizontal motion = 1.2mm,

Period of max. hor. motion = 1.0sec.

Again, the 18 earthquakes recorded at Hongo gave the following average results :—

Maximum horizontal motion = 0.37mm,

Period of max. hor. motion = 0.76sec.

The vertical component motion was always much smaller than the horizontal. (See Professor S. Sekiya's paper "Earthquake measurement, etc.," Jour. Sc. Coll., Imp. Univ. Tokyo, Vol. II.) With respect to the Tokyo earthquake measurements, it is to be remarked that at Hongo the ground is high and consists of hard loam, while at Hitotsubashi it is low and very soft.

(*d*) As illustrative of the earthquake measurement at a rocky district, I shall summarize the results obtained at the Miyako Meteorological Observatory (in the province of Rikuchu), which is situated on a small promontary of a

* *Period* means always the *complete period.*

† The reader is referred also to my recently published reports on the Tokyo macroseismic measurements, the *Publications*, Nos. 10 and 11.

palæozoic formation, about 30m in height. During the two years, June 1896 to June 1898, there were observed, with a Gray-Milne seismograph, 31 earthquakes, of which 8 were *strong*, while all the rest were *weak* or *slight*. The period of the maximum horizontal motion* varied in these 31 cases between 0.53 and 1.7 sec., giving a mean value of 1.13sec. Again, the period of the maximum vertical motion varied between 0.56 and 0.90 sec., giving a mean value of 0.71sec. The ratio of the maximum horizontal and vertical movements varied, for the different earthquakes, between 1 : 1.6 and 1 : 10, the mean result being 1 : 5.7. For an example of a *strong* movement, we may take the earthquake of Aug. 31st 1896, 4h 12m 45s p.m., which was one of the fore-shocks of the great Riku-U earthquake, and whose elements of motion were as follows :—

Maximum horizontal motion = 9mm,
Period of max. hor. motion = 0.94sec. ;
Maximum vertical motion = 1.3mm,
Period of max. vert. motion = 0.9sec.

(See Omori and Hirata's paper: "Earthquake Measurement at Miyako," *Jour. Sc. Coll., Imp. Univ. Tokyo, Vol. XI.*)

(*e*) Finally, as an example of earthquake measurement at a sandy district, I take that at Kyoto. During about 5 years, Jan. 1895 to March 1900, there were observed with a Gray-Milne seismograph 48 earthquakes, of which two were *strong* and the rest all *weak* or *slight*. The maximum horizontal motion varied between 0.1mm and 14.0mm, and its period between 0.7 and 1.04sec. ; while the greatest of the maximum vertical motion was 1.0mm, the period varying between 0.22 and 0.55sec. The mean values were as follows :—

* *Ripples* excepted.

Maximum horizontal motion = 0.51mm (EW component),

" " " = 0.50mm (NS component),

Period of max. hor. motion = 0.88sec.;

Maximum vertical motion = Small

$$\text{Period of max. vert. motion} = \begin{cases} 0.24\text{sec.} \\ 0.46\text{sec.} \end{cases}$$

(See Omori and Tojima's paper, "Earthquake Measurement at Kyoto" [Japanese], *Report of the Earthq. Inv. Comm., Vol. XXXII.*)

From what has been said above, it may be concluded that in ordinary *weak* and *slight* earthquakes, the average maximum range of motion is less than 1mm. When the range approaches 10mm, the motion becomes *strong*; when it is greater than some 50mm, the intensity becomes *violent*, brick buildings and chimneys being seriously damaged. Finally when the range reaches some 200mm, the earthquake will be very destructive. The period of vibration in the *principal*, or most strong, portion of an earthquake is about 1sec. for *weak* and *slight* movements and between 1 and 2sec. for violent and destructive ones In strong and destructive earthquakes, there are, besides the principal or fundamental vibrations, some movements whose period is much shorter and whose amplitude much smaller, than those of the latter. Further, in large earthquakes, there are slow undulations of a long period. These two classes of movements, called *ripples* and pulsations respectively, are to be excluded from our present consideration, as they have but a small effect on the overturning of bodies.

4. *Large column.* The dimensions of the column is supposed to be very large; the height being, for the sake of simplicity, further assumed to be much greater than the thickness. The earthquake motion may then be regarded approximately as acting *impulsively* at the base of the column, that is to say, the latter would be overturned by rotating about its centre of percussion relative to the base.

It is hereby to be remarked that the supposition respecting the magnitude of the dimensions of the column is virtually equivalent to the condition that the period of its rocking should be much longer than that

of the earthquake movement. Hence those columns, whose absolute dimensions are not very great, may yet be regarded as *large bodies* with regards to an earthquake motion of a very short period. Further, the deduction of formula (1) given below, which may be applied to these different cases, implies the assumption that the maximum seismic displacement occurs immediately after the termination of the *preliminary tremor* and that this motion is much larger than the succeding movements.

Fig. 1.

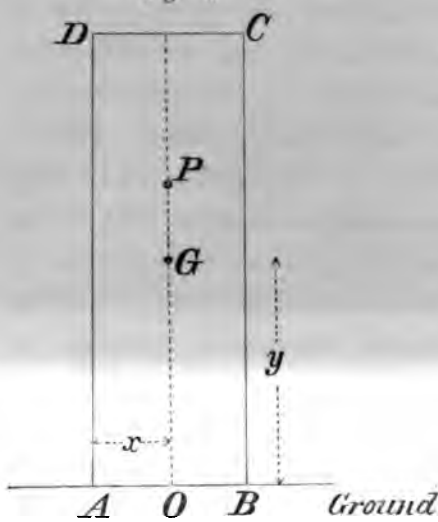
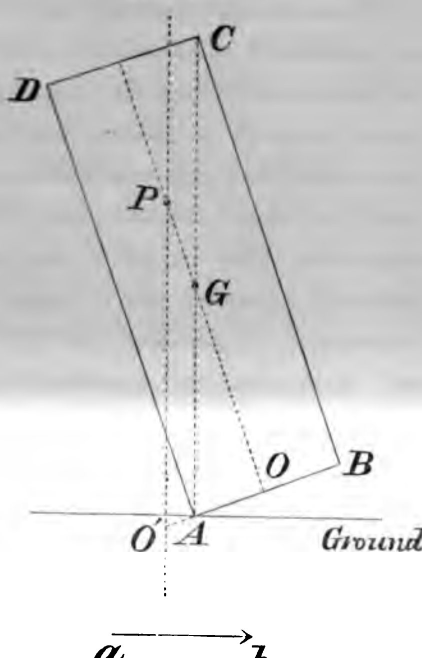


Fig. 2.



Such was actually the case in the great Tokyo earthquake of 1894, which was satisfactorily recorded instrumentally at Hongo. Further, the directions of overturning of various bodies were found to be regular at Nagoya and other places in the meizoseismal area of the Mino-Owari earthquake of Oct. 28th 1891. So it was also the case in the epicentral tract of the Shōnai earthquake of Oct. 22nd, 1894. These facts lead to the conclusion that the character of motion in destructive earthquakes must be comparatively simple, as above supposed.

Let $ABCD$ (Fig. 1) be a rectangular column, resting on the ground, G being its centre of gravity. Let $2y$ and $2x$ be respectively the height and the thickness of the column; y being supposed to be several times greater than x. If P is the centre of percussion of the column with respect to the base AB, its height is given by the following equation:

$$OP=\left(\frac{x^2+y^2}{3}+y^2\right)\div y = \frac{x^2+4y^2}{3y}.$$

If now the ground move suddenly from a to b (Fig. 2), the column $ABCD$ would rotate about the point P as centre, and may be upset when the amount of rotation is so great that the centre of gravity G is brought vertically above the edge A, as shown in the figure. Let O' be the point of intersection of the base AB and the vertical through the point P, then the distance OO' may be taken as representing approximately the range $(=2a)$ of the earthquake motion. We obtain therefore

$$\frac{\overline{GO}}{\overline{OA}}=\frac{\overline{PO}}{\overline{OO'}},$$

or

$$2a=\overline{OO'}=\frac{\overline{OA}\times\overline{OP}}{\overline{OG}}=\frac{x(x^2+4y^2)}{3y^2}, \qquad (1)^*$$

which gives the least value of the range $(2a)$ of the earthquake motion necessary for upsetting a rectangular column of the dimensions $2y\times 2x$.

Equation (1) shows that the value of the $2a$ depends not simply on the ratio $\frac{y}{x}$, but also on x. Hence the earthquake motion necessary for overturning a column, whose height and base are in the ratio of $\frac{y}{x}$, increases with the absolute dimensions of $2x$ and $2y$. As an illustration, I give in the next table a few values of $2a$ corresponding to the ratio $\frac{y}{x}=4$.

* Equation (1) is a slightly modified but practically identical form of a formula, which I have given in *Seism. Jour. Japan*, Vol. II.

$2x$ (inches)	$2y$ (inches)	$2a$ (inches)
1	4	0.7
2	8	1.4
..	..	..
12	48	8.1
..	..	..

If the column $ABCD$ is not a rectangular prism, as above suppose but a body of any form with a central axis, we have, instead of (1), t following :—

$$2a = \frac{\overline{OA} \times \overline{OP}}{\overline{OG}} = \frac{x}{y} \times h = \frac{xk^2}{y^2}, \tag{2}$$

in which $y = \overline{OG}$; $h = OP$; G and P have the same signification before ; $2x$ is the thickness at the base ; and k is the radius of gyratic of the column with respect to the base, or what is practically identic with respect to the point O.

5. *Examples of large bodies.* As an illustration, let us suppose square uniform column for which $\frac{y}{x} = 5$, $2x = 20$ft, and $2y = 100$ Equation (1) then gives $2a = 14$ft. This means that such a lar column would require for the overturning at least an earthquake motic of some 14ft. Again, if $2x = 10$ft and $2y = 50$ft, we obtain $2a = 6.7$ Now even the range of motion at Nagoya on the occasion of the gre Mino-Owari earthquake of 1891 was about 233mm or 9 inches ; a large movements of 6 or 14ft is not likely to occur even in a very viole destructive earthquake. Hence, according to equation (1), such lar columns as here supposed would never be overturned by an earthquak however violent.

As practical examples of *large columns*, I may mention *gojūno* (five-storied pagoda) ; *sanjūnotō* (three-storied pagoda) ; *hinomiyagu* (towers for fire bells) ; bell towers of temples, etc. These buildings a

simply put on stone blocks fixed to the ground, but would never be overturned as a whole by an earthquake, except in those cases when their *ishigaki* or masonry foundations give way. Further, they are only little affected by earthquakes, since they are strong in structure and are essentially each a compact single body, being much different from ordinary houses whose construction is so heterogeneous, that is to say, composed of a number of different frame works. Especially, *gojūnotō* suffers so little from earthquakes, that people generally imagine that there must be some mystery in their construction for rendering them earthquake-proof. The principal reason lies, however, merely in the fact that their dimensions are large.

Fig. 3. The Gojūnotō at Asakusa, Tokyo.
(Ansei Earthquake, 1855.)

Brick factory chimneys are usually broken at about ⅔rd of the height. (See the *Publications*, No. 4.) Now it happens very often

that the fractured portions are simply displaced or rotated, but not fall down. This is probably due to the fact that the dimensi of the chimneys, or of the broken top portions, are much greater t the range of the earthquake motion.

6. *Gojūnotō* (five-storied pagoda). The annexed figure, which taken from a book entitled "Ansei Kenmonshi," shows the condit of the *gojūnotō* at Asakusa, Tokyo, after the great Ansei earthqu of 1855; the upright metal post at the top was bent into a cu shape, the structure itself, however, remaining undamaged. On occasion of the great Mino-Owari earthquake of 1891, there were Nagoya a *sanjūnotō* (three-storied pagoda) and a *gojūnotō*, both having been damaged; while a very old *sanjūnotō* in the tem ground of Hiyoshi at the town of Gôdo (province of Mino), had top metal post broken at its base and thrown down to the grou the building remaining otherwise undamaged.

7. *Bell towers.* Fig. 5, Pl. VII., represents the condition af the great Shōnai earthquake of Oct. 22nd, 1894, of the bell tower a temple called Anjōji in the city of Sakata. The main tem building itself was greatly damaged by the shock and caused incline much toward the east, and was four days later crushed the ground. The bell tower which stood on a platform about ft square and 3 ft high, was not overturned, but rotated ab 18° clockwise. (See also Fig. 4.) *a b' c' d'* represent the origi and *a b c d* the displaced, positions of the four posts, the column having remained unshifted. Structures like these, which are t heavy, are nevertheless not overturned by earthquakes unless th platforms are cracked or the supporting posts give way at the juncti with the roof.

8. *Chimneys.* Chimneys* are easily broken by earthquakes. happens, however, very often that the broken portion remains, eit entirely or partly, in its position, suffering only displacement

* *Chimney* means here a brick factory chimney.

rotation. Numerous such cases occurred in the Tokyo earthquake of 1894. (See the *Publications*, No. 4, pp. 117–124.). The following two cases relate to the Mino-Owari earthquake.

Chimney of the Cement Factory, Nagoya. The top of the chimney, whose total height was 85 *shaku*† was broken in pieces and thrown down toward W and N. The remainder was fractured at three different heights; the broken portions did not fall down, but rotated each slightly clockwise.

Chimney of the "Kasōjo," Gifu. The chimney, whose total height was 50 *shaku*, had its top portion, about 12 *shaku* in length, broken and thrown down toward WSW to a distance of about 27 *shaku* from the base. The remainder of the chimney was fractured at two different places; but the broken parts did not fall down, each having slightly rotated clockwise.

To determine the range of earthquake motion, necessary to overturn a chimney *as a whole*, which can only occur when the tensile strength of the brick work at the base is *nil*, let us take as an example the chimney of the Ōji Goryōkyoku Factory, near Tokyo.* The section of the chimney, whose height was 100 ft, was circular; the external diameter being 13.4 *shaku* $(=2x)$ at base and 7.2 *shaku* at top. The height (h) of the centre of percussion and the height (y) of the centre of gravity, found by calculations, were 54.4 and 33.9 *shaku* respectively. The earthquake motion $(=2a)$ necessary for overturning the whole structure is therefore

$$2a=\frac{x}{y}\times h=\frac{6.7\times 54.4}{33.9}=10.8 \textit{ shaku},$$

which is much greater than anything likely to occur in actual destructive earthquakes.

The above calculation is of course to be regarded as a gross approximation. Still we see that no earthquake motion, however

† 1 *shaku* = 0.994 foot.

* For the calculation of the seismic strength of this chimney, the reader is referred to the *Publications*, No. 4, p. 123.

great, would be able to overturn a large chimney as a whole. It is hereby to be noticed that the phenomenon of overturning is totally different from that of fracturing.

9. *Small column.* The column is to be regarded as a small body, when its period of rocking is not much greater than the period of the earthquake motion. These cases have already been discussed in the *Publications*, No. 4, pp. 124–137; the acceleration (a) necessary for overturning a body being, according to the method of Professor C. D. West, given by the formula

$$a = g \times \frac{x}{y}, \qquad (3)$$

where x is half the dimension of the base of the column, supposed to have an upright central axis, and y is the height of the centre of gravity.

Equation (3), which holds good when the earthquake motion is not very small in comparison to the dimension of the base, may be used in the cases of the overturning of the tomb stones,† *ishidoro*,* etc., in a destructive earthquake, but not to the overturning of such large bodies as chimneys, *gojūnotō*, etc. The *ripples*, which often exist in *weak* and *strong* earthquakes, have usually very high values of accelerations. These are, however, unable to produce the phenomena of overturning on account of the smallness of amplitude.

10. *Examples of columns overturned by earthquakes.* Figs. 6 and 7, (Pl. VIII), show respectively tomb stones and a *ishidoro*, at Sakata, overturned by the earthquake of Oct. 22nd 1894.

To give an idea respecting the columns overturned, as well as those not overturned, by destructive earthquakes, I shall next mention some of the cases observed at Nagoya and Ōgaki, which were very severely damaged by the great shock of Oct. 28th 1891; the number

† A Japanese tomb stone consists usually of a square or rectangular post of uniform section put on pedestals.

* *Ishidoro* are Japanese stone lamp posts for gardens, which are found in great number in temples, and consist generally of a cylindrical or square stem, on which chamber for holding light is put, the different parts being usually not cemented together.

Fig. 4. Rotation of the Bell Tower of Anjōji, Sakata.

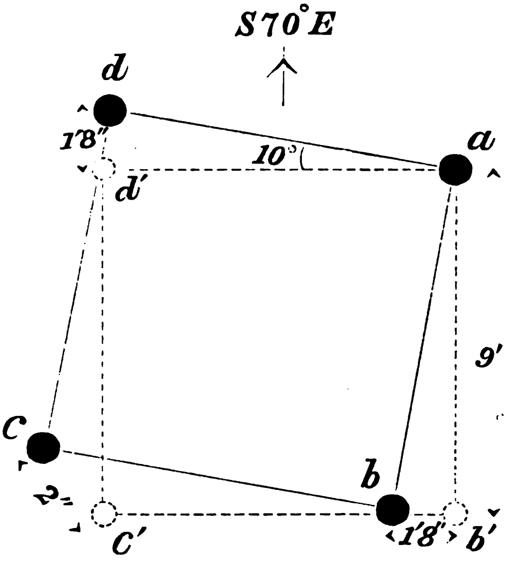


Fig. 5. The Bell Tower of Anjōji, Sakata.

Fig. 6. Overturned tomb stones, Sakata.
Earthquake of Oct. 22nd, 1894.

Fig. 7. An overturned *ishidorō*, or stone lantern, (Sakata).
Earthquake of Oct. 22nd, 1894.

of the dwelling houses totally destroyed in these two cities amounting to 3 and 80% respectively. The a's given in the tables have been calculated from equation (3).

Nagoya.

(a) Observations at a temple called Daikōji. The temple, which is in the northern part of the city, was not much damaged, but inclined somewhat toward W. The temple gate, or *sammon*, which suffered only slight damage, such as falling down of plasters, was displaced bodily 45 mm toward W. Some of the tomb stones observed were as follows.

Form of Section.	Sectional Area.	Height.	$a=g\times\frac{x}{y}$ (mm/sec.^{2})	REMARKS.
Square	cm 30×30	cm 76	3900	Not overturned.
,,	,,	,,	,,	Not overturned, but rotated together with its pedestal (24×47×47cm) 5° clockwise.
,,	33×33	92	3500	Overturned.
,,	,,	,,	,,	Not overturned, but rotated 30° clockwise.
,,	,,	96	3400	Not overturned, but was displaced 2,5cm toward W.
Rectangle (Longer side parallel N-S.)	30×21	75	2700	Overturned toward W.
,,	30×19	78	2400	,,
,,	34×25	75	3300	,,

(b) Observations at a temple called Kenchūji. The temple, which is in the NE part of the city, was not damaged. There were several hundred well constructed tomb stones and *ishidoro*, which gave an excellent material for the determination of the direction and intensity of the shock; there being no moat, cliff and the like, which

Ōgaki.

The following table gives the observations made at a temple called Entsūji, in Ōgaki.

Form of Section.	Sectional Area.	Height.	$a=g\times\frac{x}{y}$ (mm/sec.²)	REMARKS.
Square.	cm 27 × 27	cm 66	4000	Not overturned.
"	15 × 15	44	3300	" "
"	23 × 23	60	3800	Not overturned, but was displaced 2cm toward S.
"	23 × 23	60	3800	Not overturned, but rotated 35° clockwise.
"	22 × 22	72	3000	Overturned.
"	25 × 25	65	3800	Overturned toward S.
Rectangle (Longer sides parallel E-W.)	22 × 14	50	2700	Overturned normally to its faces.
Rectangle (Longer sides parallel N-S.)	35 × 22	95	2300	Do.

From the observations above given as well as from many others, I have e timated the intensities at the two cities of Nagoya and Ōgaki to be respectively 2600 and 3000 $\frac{\text{mm}}{\text{sec.}^2}$

11. " *Shaking Table* " *experiments.**

A wooden box, whose height was 484 mm and whose section was 242 × 242 mm, was put on the *shaking table* and tried with the most violent motion which the latter was able to produce. Thus, in one experiment the maximum horizontal motion of the latter was $2a=119$ mm, $T=0.51$ sec.,† maximum acceleration $=9000\ \frac{\text{mm}}{\text{sec.}^2}$; while in another experiment, the maximun motion was $2a=120$ mm,

* Extracted from my paper " Seismic Experiments, etc.," the *Publications*, No. 4.

† $2a$ denotes the range of motion and T the complete period.

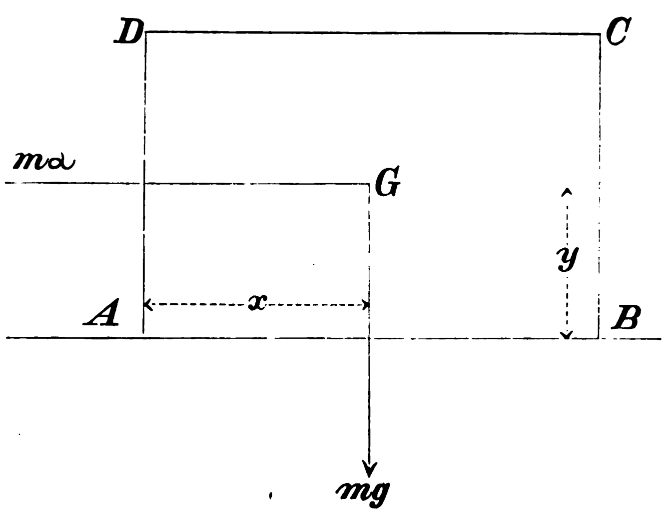
T=0.47 sec., maximum acceleration=10700 $\frac{\text{mm}}{\text{sec.}^2}$. The column was, however, not overturned.

That the acceleration of the shaking necessary for overturning a given column does not depend on the material of the latter has already been shown in the *Publications*, No. 4, p. 137, where brick, iron, and wooden columns were compared with each other.

From these experiments as well as from the examples given in § 10 we can form a fairly good idea respecting the bodies likely to be overturned in destructive earthquakes. Equation (3) is to be used when the basal dimension of a tall column is less than some 30 cm, while equations (1) and (2) are to be used when it is above the latter limit.

SLIDING OF BODIES.

12. A body, resting on the ground, is sometimes never overturned by an earthquake, however strong, but suffers simply a displacement.



Let $ABCD$ be a body, supposed for simplicity's sake, to be a rectangular solid, resting on the frictional surface AB; G being the

centre of gravity. Let $2x$ be the dimension of the base and $2y$ the height. If g be the acceleration due to gravity, m the mass of the body, and a the acceleration of the earthquake motion supposed to be horizontal. Then there are two forces mg and ma acting at the point G, the former vertically downwards and the latter horizontally. If now the force ma is about to overturn the body, with the corner point B as centre, we have the following relations among the pressure (P) and the friction (S), which act at the point B downwards and in the direction BA respectively;

$$P = mg;$$

$$may = mgx, \text{ or } a = g \times \frac{x}{y};$$

$$S = ma = mg \times \frac{x}{y}. \qquad (4)$$

Now S can not become greater than μmg, μ being the coefficient of friction. Hence, according to equation (4), the the above relations do not hold if the ratio $\frac{x}{y}$ is greater than μ. The body would then be not overturned, but begin to slide. Thus flat bodies, or those for which x is great in comparison to y, are never overturned by an earthquake, but may suffer a sliding when the intensity of motion becomes sufficiently great. It is owing to this reason that in the areas of violent shakings some tomb stones, temple gates, *dozō* (Japanese ware-houses), houses, etc., are displaced from their foundations. When the motion is sufficiently violent, the bodies may be projected. I give next some of the most remarkable examples of the displacement of bodies observed in the great Mino-Owari earthquake of 1891 and the Shōnai earthquake of 1894.

13. Displacement of *ishidoro* (Mino-Owari earthquake).

(*a*) At the village of Kōdokoro, in the Néo-Valley,* province of Mino, there were, in front of a small Kasuga temple by the road

* The epifocal tract of the great earthquake.

side, two similar *ishidoro* (Fig. 11, *a*) with cylindrical stems, whose condition after the earthquake indicated the great violence of the shock, both columns having been scattered about except their foundation stones fixed to the ground.

One of the *ishidōro* (Fig. 11, *b*) had the stem and the upper parts projected toward N80°W, while the two base plates B and C were together thrown towards NW; the plate B, whose centre of gravity in the displaced position was 2′ 6″ from the original, having got entirely out of the foundation stone A.

The other *ishidōro* (Fig. 11, *c*) had its stem and the upper parts irregularly projected toward NE, except the top plate which fell toward E. The two base plates were thrown toward opposite directions, namely, the upper plate C′ toward N35°W and the lower plate B′, composed of two halves, toward S40°E. The centre of the latter plate was displaced 40cm. while the displacement of the former plate amounted to more than 38cm.

(b) (Pl. X.) On a hill to the east of the village of Nakamura, also in the Néo-Valley, a small temple was thrown down eastwards. In front of the temple there were two similar *ishidoro* (Fig. 12, *a*) with square stems, which were shattered in a remarkable manner by the shock.

Of the two *ishidoro* (Fig. 12, b), one had its stem thrown toward W and the upper parts toward E. It is hereby to be noted that these directions of overthrowing were not normal to the faces of the foundation plate, whose sides were parallel to N30°W–S30°E and E30°N–W30°S. The base plate B, whose centre of gravity was moved 1′ 3″ from the old position, got nearly out of the foundation plate A fixed in the ground.

The other *ishidoro* (Fig. 12, *c*) had its stem and upper parts thrown toward E. The base plate B was displaced about 9″ toward W on the foundation plate A′.

The directions in which these two *ishidoro* were overturned or displaced were not normal, but parallel, to the contour lines of the

hill; so that in this case, the direction of the earthquake motion was not modified by the slope of the ground.

14. *Displacement of "sammon" (temple gate) and ware houses.* * (Mino-Owari earthquake).

(a) (Pl. XI.) At Kimbara, in the Néo-Valley, which together with the two villages of Kōdokoro and Nakamura above mentioned was in the most strongly shaken zone, there was produced a fault across the village ground and all the buildings were destroyed with the single exception of the temple gate (Fig. 13, *a*), which essentially consisted of six strong vertical posts, each 12 *shaku* high, supporting a tiled roof. The base of each post rested on a circular disc of stone, which in its turn rested on a small square foundation stone fixed to the ground. The temple gate, which suffered no damage except the shaking down of some tiles from the edges of its roof was displaced 3 *shaku* towards ESE nearly in the direction of one of its diagonals (Fig. 13, *c*). From a close examination of the prints left clearly by the feet of the posts on the ground which was soft, I have ascertained that the displacement was the result, not of a gradual sliding, but of two successive jumpings or projections (Fig. 13, *d*); the first projection having, however, brought the structure near to the final position. The circular base stones suffered also displacements, but were left not far from their initial positions. One of the posts of the gate got after the displacement accidentally on a neighbouring base plate, evidently with a considerable force, as the latter, 6 inches thick, was entirely buried in the ground. This shows that at Kimbara both the horizontal and the vertical movements were very strong indeed.

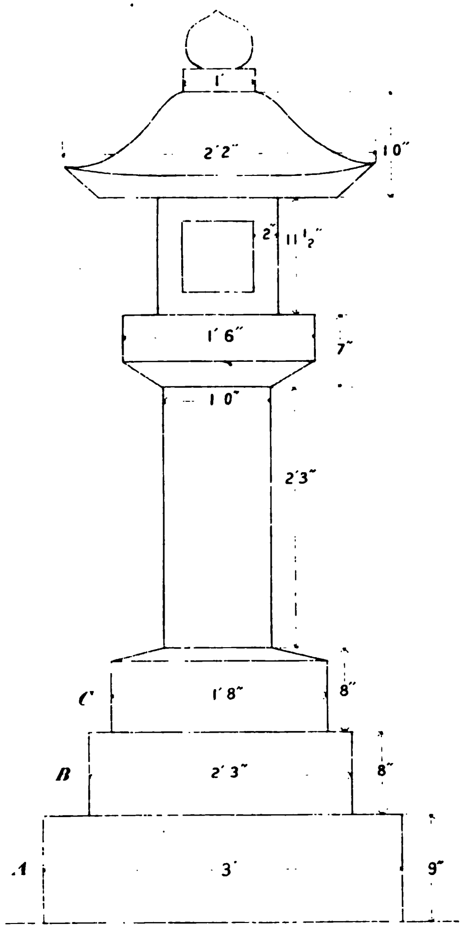
(b) At the village of Ōi, also in the Néo-Valley, there was, on a flat piece of ground cut in the slope of a hill, a small ware house (Fig. 14), which was 18 *shaku* long and 12 *shaku* wide, and which

* Japanese wooden buildings consist generally each of a frame of beams simply put on stone foundations fixed to the ground.

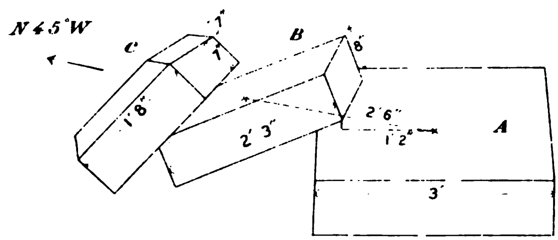
FIG. 11. *ISHIDŌRO* AT KŌDOKORO, NEO-VALLEY, MINO.

Earthquake of Oct. 28th 1891.

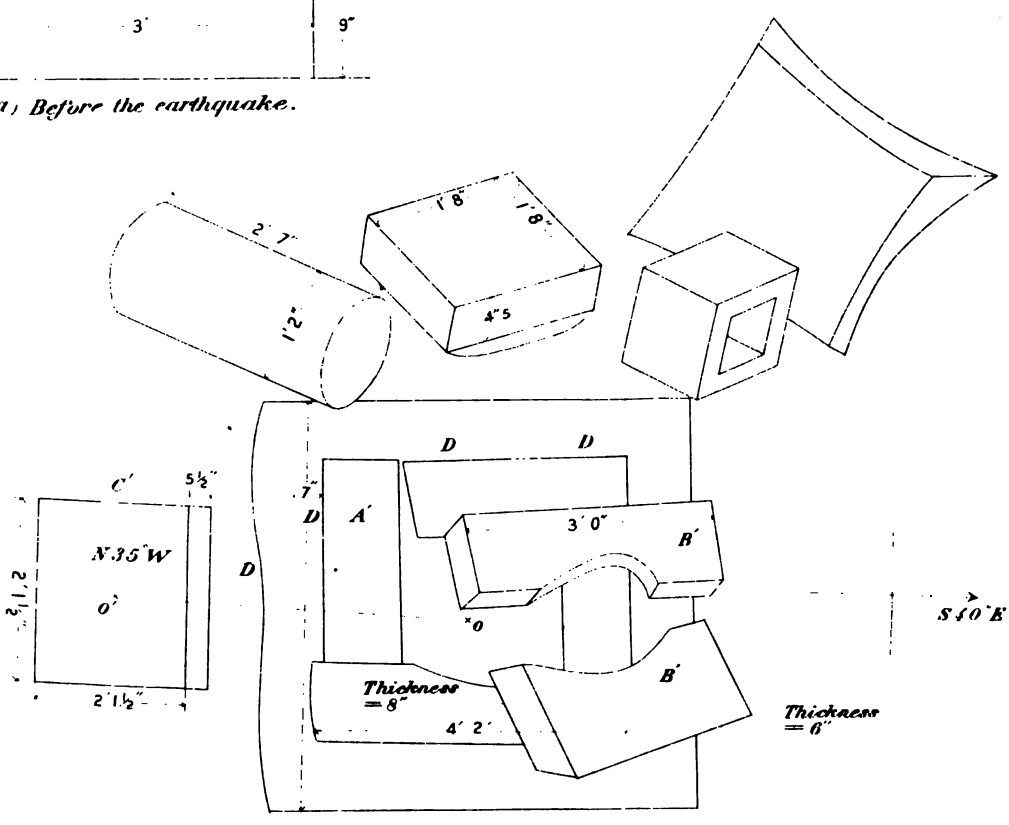
(Dimensions are given in feet and inches.)



(a) Before the earthquake.



(b) Displacement of the base plates of one of the "ishidoros."



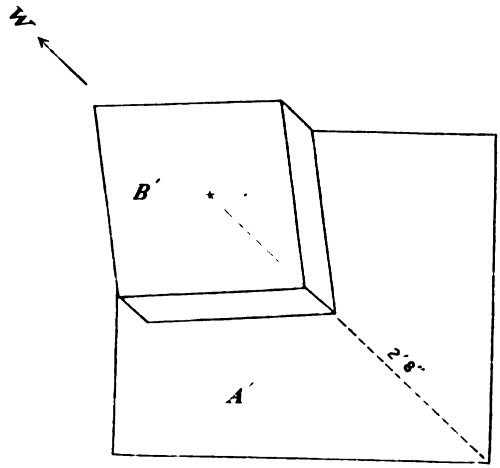
(C) Overturning and displacement of one of the "ishidoros."

Fig. 12.

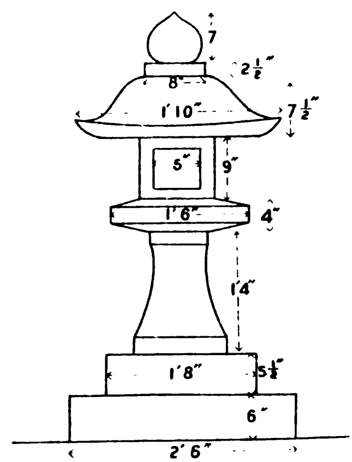
ISHIDŌRO AT NAKAMURA, NEO-VALLEY, MINO.

Earthquake of Oct. 28th 1891.

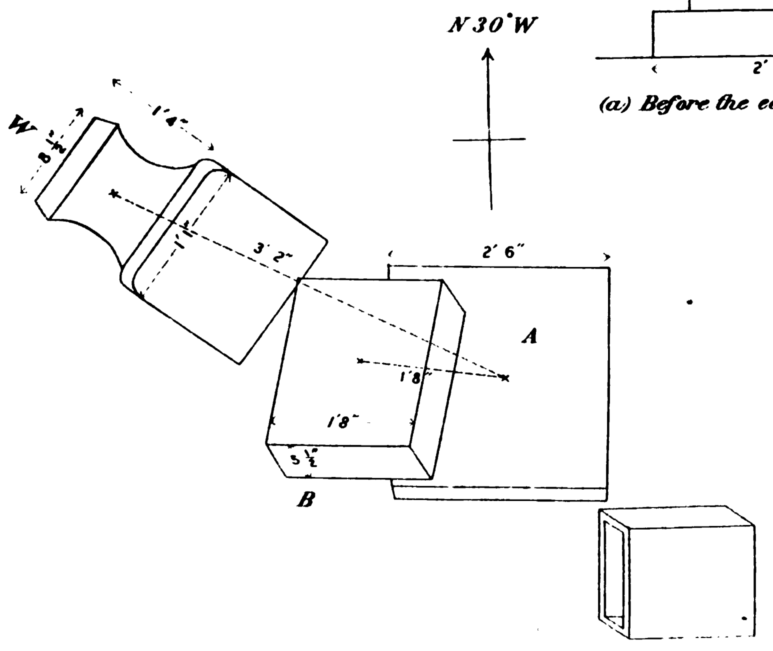
(Dimensions are given in feet and inches.)



(C) Displacement of the base plate of one of the "ishidoro's"



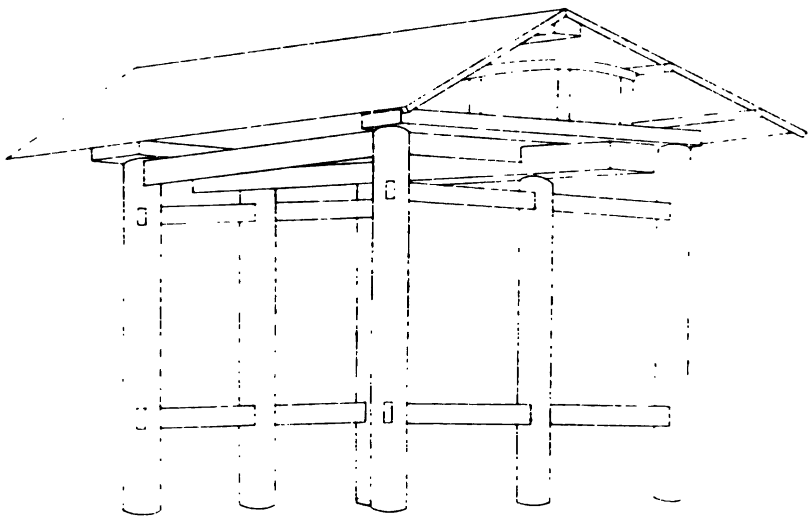
(a) Before the earthquake.



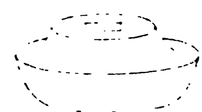
(b) Overturning and displacement

FIG. 13. THE *SAMMON*, OR TEMPLE GATE AT KIMBARA, NEO-VALLEY.

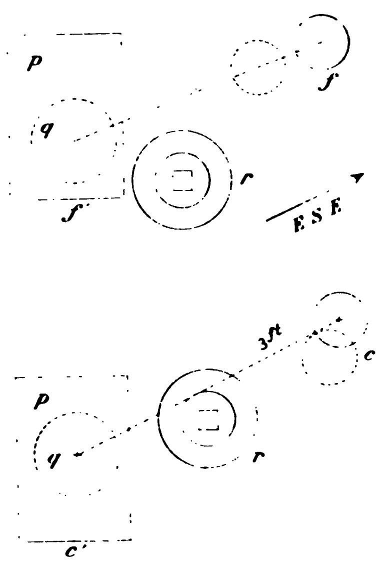
Earthquake of Oct. 28th 1891.

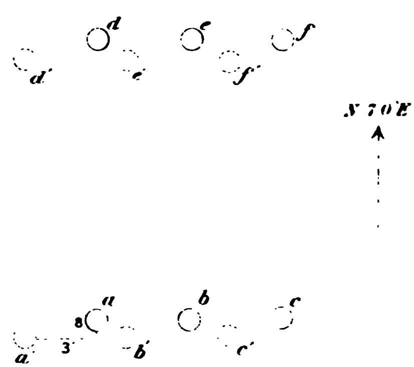


(a) The "sammon" or temple gate.



(b) Base of each post.



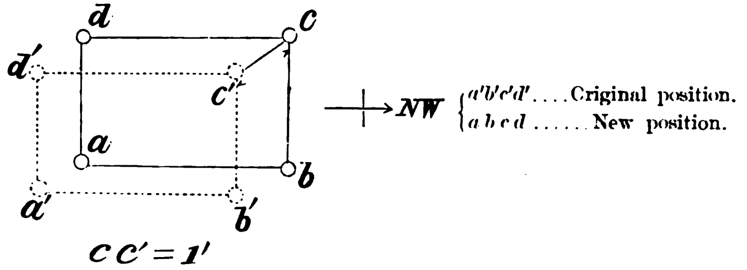


(*d*) Displacement of the two posts *f'* and *c'*. *pp* are the foundation stones and *qq* the positions where the two bases *rr* originally rested; dotted circles near *f* and *c* being the prints left by the posts.

(c) *a' b' c' d' e' f'* are the old and *a b c d e f* the displaced positions of the gate posts.

consisted essentially of four vertical corner posts, supporting a thatched roof. The structure suffered no particular damage, but was shifted entirely off the foundation stones about 1 *shaku* toward N60°W.

Fig. 14



The displacement took place evidently by a single projection, as the feet of the posts were each buried about 1 inch in the ground and there was no sign of a gradual sliding on the surface of the latter.

15. *Displacement of a house.* (Shōnai earthquake). At the village of Asuka, in the province of Uzen, a dwelling house with plastered walls, and 60 × 30 *shaku* in area, whose longer side was parallel S 38° W–N 38° E, was found dislodged from the foundation stones and displaced 1.7 *shaku* toward S 85° W. The village was in the epicentral zone of the Shōnai earthquake.

16. From examples given in §§ 13–15, which are some of extreme cases found in very strongly shaken districts, we can form an idea respecting the displacements of wooden and other structures likely to happen in cases of very great earthquakes.

May 1900. Tokyo.

Note on the Vibration of Chimneys.

By

F. Omori, *Rigakushi*, *Rigakuhakushi*,

Member of the Imperial Earthquake Investigation Committee.

With Plates XII-XVI.

1. *Introduction.* The period of natural vibration or of rocking of a body is a very important factor in the discussion of the overturning and fracturing phenomena. If this period be much greater than that of the earthquake motion, the body may be regarded as rotating about its centre of percussion with respect to the base. In other cases, however, the body is to be supposed as being acted on by a force equivalent to the product of its own mass and the maximum acceleration of the earthquake motion applied at its centre of gravity. From these considerations, I have distinguished different structures in the case of overturning into *small* and *large* bodies,* and in the case of fracturing into *short* and *tall* bodies.†

The discussion of the seismic stability of chimneys,‡ which I have given in the *Publications*, No. 4, pp. 117-124, is based on the supposition that their vibration is much slower than the earthquake motion. It is extremely desirable to measure the movements of some large chimneys; experimental investigation in this connection being yet very scarce.

The present note gives the results of the instrumental registration of the vibration of two small chimneys, which I have recently carried on in Kyoto and Tokyo respectively.

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* This volume, p. 8.

† The *Publications*, No. 4, pp. 76, 121.

‡ A *chimney* means here a brick factory chimney.

2. *Chimney of the Institute of Mechanical Engineering, Kyoto Imperial University.* (Dec. 3rd and 4th, 1900.)

The chimney (Pl. XIII), constructed about two years before the date of the experiments, is 51 *shaku*[*] high, and square in section, the thickness of the wall being as follows:—

for the lowest 6 *shaku*, ...2 bricks, or 1.54 *shaku* ;
,, ,, middle 7 ,, ...$1\frac{1}{2}$,, ,, 1.15 ,, ;
,, ,, upper 38 ,, ...1 brick, ,, 0.75 ,, .

The record-receiver,[†] on which the vibration in question was recorded, was put up on an independent frame of wooden beams specially erected close to the chimney; the writing index being a pen hinged to the end of a strong brass rod firmly attached to the top of the latter. The observer himself got also on the top of the wooden frame, whence the chimney was seen to oscillate gently with every blow of moderate wind. The chimney was caused to vibrate by cutting suddenly a rope fastened to it, whose end passed over a pulley and carried a stretching weight. The pulley was fixed to the top of a triangular frame of wooden beams, whose height was 24′ 9″ and whose horizontal distance from the base of the chimney was 53′ 7″. (See Pl. XII, Fig. 1.) The observation was repeated three timess with different stretching weights.

Two of the diagrams obtained are reproduced in Pl. XIV; the rate of motion of the paper being accurately gauged by means of a small time ticking pendulum, whose complete oscillation, corresponding to two successive tick intervals in the records, was 0.68 second.

The results of the experiments are summarised in the following table.

[*] 1 *shaku* = 0.994 foot.

[†] The record-receiver was similar to that used in the *Seismic experiments* (the *Publications*, No. 4) and consists of white paper moved by two rollers by means of a clock-work.

TABLE I.

VIBRATION OF THE CHIMNEY OF THE INSTITUTE OF MECHANICAL ENGINEERING, KYOTO.

{ 2a = Range of motion, or double amplitude at the top.
T = Complete period of vibration.

		1st. Expt.	2nd. Expt.	3rd. Expt.
Stretching weight.		24.5 kg	59.0 kg	67.0 kg
Its horizontal component.		22. "	53. "	60. "
Initial, or maximum, 2a.		4.6 mm.	7.4 mm.	8.1 mm.
1st 10 vibrations	——	——	——	——
	Average T.	1.04 sec.	0.99 sec.	1.03 sec.
2nd 10 vibrations	Max. 2a.	2.3 mm.	3.5 mm.	4.5 mm.
	Average T.	1.02 sec.	1.01 sec.	1.02 sec.
3rd 10 vibrations	Max. 2a.	1.45 mm.	2.0 mm.	3.0 mm.
	Average T.	0.99 sec.	0.99 sec.	1.02 sec.
4th 10 vibrations	Max. 2a.	1.0 mm.	1.2 mm.	1.45 mm.
	Average T.	0.99 sec.	0.99 sec.	1.01 sec.
Toward the very end	Max. 2a.	——	——	Very small.
	Average T.	——	——	1.01 sec.
General mean T.		1.01 sec.	1.00 sec.	1.02 sec.

Thus the mean value of the average period of vibration was about 1.01sec., the maximum or initial range of vibration being 8.1mm. The horizontal or effective stretching forces were in the three experiments 22, 53, and 60 kg respectively; the deflections of the chimney at the

top due to these different weights being half the initial ranges of motion, or 2.3 ; 3.7 ; and 4.1mm respectively.

The observation was not made with very great stretching weights, lest damage should happen to the chimney, which was evidently a very flexible one, due probably to bad quality of the mortar and to its slender form. Had the stretching been carried so far that the initial (top) range of motion amounted to 2 or 3 inches, the period of vibration would be considerably increased. I believe that the period of vibration of the chimney would, on the occasion of a destructive earthquake, amount to 2 seconds or more.

3. *Chimney of the Hygienical Institute, Tokyo Imperial University.* Oct. 3rd and 4th, 1901.

The chimney of the Hygienical Institute[3] was square in section and only 24 *shaku* in height, the thickness of the wall being as follows:—

the lower 13.6 *shaku*, ...1.2 *shaku* thick,
„ upper 10.6 „ , ...0.7 „ „ .

The mortar contained no cement, but was composed probably of 4 parts of lime and 6 parts of sand. (See Pl. XII, fig. 2; and Pl. XV.)

The method of observation was exactly similar to that in the preceding case, except that the rope fastened to the top of the chimney was drawn gradually by means of a lever arrangement managed by a few men. The experiments were repeated five times; the chimney having been finally broken in the 5th experiment at about 2 feet from the base. The diagrams obtained in the 3rd to 5th experiments are reproduced in Pl. XVI; the complete period of the time-ticking pendulum being here 0.73 second.

The results of the experiments were as follows.

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3) A flat wooden building burnt down in 1901.

TABLE II.

VIBRATION OF THE CHIMNEY OF THE HYGIENICAL INSTITUTE, TOKYO IMPERIAL UNIVERSITY.

$\begin{cases} 2a = \text{Range of motion, or double amplitude at the top.} \\ T = \text{Complete period of vibration.} \end{cases}$

Expt.	Absolute maximum, or initial, 2a (mm)	1st 10 Vibrations	2nd 10 Vibrations		The next 20 Vibrations	
		Average T (sec).	Max. 2a (mm).	Average T (sec).	Max. 2a (mm)	Average T (sec).
1	7.2	0.35	2.6	0.34	0.9	0.34
2	5.2	0.34	2.0	0.34	0.9	0.33
3	17.2	0.37	4.5	0.34	1.2	0.34
4	19.2	0.36	4.5	0.35	1.8	0.34
5	(Broken at an initial displacement, $a=19$mm).					

Thus the average period of vibration of the chimney was 0.36 or 0.37 sec. with a large initial 2a of 17 to 19mm, while it was distinctly smaller and equal to 0.34 sec. with very small amplitude.

NOTES.

In the 4th experiment, the 2a's of the first 20 successive vibrations were as follows:—

17.8 mm	7.0 mm	3.0 mm
15.0	6.1	2.9
13.3	5.5	2.3
11.9	4.9	2.0
10.2	4.0	1.9
9.0	3.8	1.9
8.0	3.2	

The motion became practically *nil* at 19.7 seconds from the commencement, after having executed altogether about 57 vibrations.

In the 5th experiment, the column was broken while the rope was being stretched, probably at a deflection, a=19 mm. The 2a just after the fracture, or the top motion due to the initial rocking, was 58.5 mm, and its period 0.58 sec.; the amplitude thence rapidly decreasing. The first five vibrations lasted together 2.3 seconds, so that the average period was 0.45 sec., the 2a of the last (5th) vibration being 15.8 mm. The next five vibrations lasted together 2.2 seconds and had an average period of 0.44 sec., the 2a of the last (10th) vibration being 1.9 mm. The motion lasted 9.2 seconds more, the successive 10;10; and 5 vibrations giving average periods of 0.39;0.36; and 0.34 sec. respectively. It will thus be seen that, in the 5th experiment, the amplitude decreased very rapidly and the period of the very small oscillations was essentially the same as that before the fracture of the chimney.

Tensile strength of the brick work. After the above experiments, a number of test pieces were made from the brick work fragments of the chimney and their tensile strength was determined by means of a testing machine in the Workshop of the Engineering College; the test pieces of the form (*a*) giving the strength of the joint, while the pieces of the form (*b*) that of the bricks. The result was as shown in Table III, the mean tensile strength of the joints being 23.5 lbs per square inch, and that of the bricks 144 lbs per square inch. The test pieces have been taken from the base, the middle and the top parts of the chimney respectively.

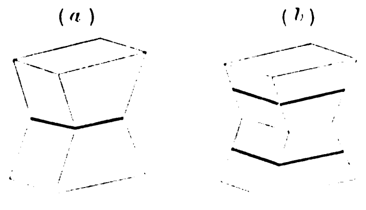


TABLE III.

CHIMNEY OF THE HYGIENICAL INSTITUTE, TOKYO IMPERIAL UNIVERSITY.

(*a*) Tensile strength of the joints.

17 test pieces taken from the lowest part of the chimney.		17 test pieces taken from the middle part of the chimney.		15 test pieces taken from the upper part of the chimney.	
Tensile strength. lbs per □″	Remark.	Tensile strength. lbs per □″	Remark.	Tensile strength. lbs per □″	Remark.
38.9	Broke through mortar.	45.1	Broke by separation.	11.0	Broke through mortar.
16.8	„	42.6	Broke $\frac{3}{4}$ through mortar, $\frac{1}{4}$ by separation.	15.5	„
56.5	„	46.9	Broke through mortar.	32.3	„
5.6	„	15.8	„	24.4	Broke mostly through mortar.
6.6	„	31.7	Broke mostly by separation.	16.6	Broke through mortar.
41.4	„	27.4	„ by separation.	11.7	„
11.9	„	19.5	Broke $\frac{1}{2}$ through mortar and $\frac{1}{2}$ by separation.	20.5	Broke mostly through mortar.
36.5	Broke mostly through mortar, the rest by separation.	10.2	Do.	34.2	Broke through mortar.
19.4	Broke through mortar.	32.7	Broke through mortar.	22.2	„
14.6	„	43.4	Broke mostly through mortar.	34.5	„
15.9	„	42.9	„ through mortar.	10.5	Broke mostly through mortar.
10.6	„	13.9	Broke mostly by separation.	30.5	Broke through mortar.
25.1	„	9.9	Broke mostly through mortar.	33.5	„
10.6	„	23.8	„	16.1	„
21.5	„	24.1	Broke through mortar.	17.2	Broke by separation.
7.5	„	27.2	„		
13.6	Broke by separation.	10.2	Broke mostly through mortar.		

20.8 (mean). 27.5 (mean). 22.0 (mean).

(*b*). Tensile strength of the bricks.

10 test pieces taken from the lowest part.	9 test pieces taken from the middle part.	9 test pieces taken from the top part.
lbs per □″ 135.2	lbs per □″ 135.5	lbs per □″ 136.1
195.7	241.2	138.0
150.6	171.0	136.9
199.9	118.9	129.6
170.5	86.3	104.6
120.9	121.5	136.9
132.1	122.3	136.1
139.6	107.1	138.5
135.0	142.1	156.1
202.8		
158 (mean).	138 (mean).	135 (mean).

LIST OF PLATES.

Time marks: the value of two consecutive tick intervals, corresponding to one complete oscillation of the time-marking pendulum, is 0.68 sec. in Pl. XIV, and 0.73 sec. in Pl. XVI.

Fig. 1.
Chimney of the Institute of Mechanical Engineering,
Kyoto Imperial University.

Fig. 2.
Chimney of the Hygienical Institute, Tokyo
Imperial University.

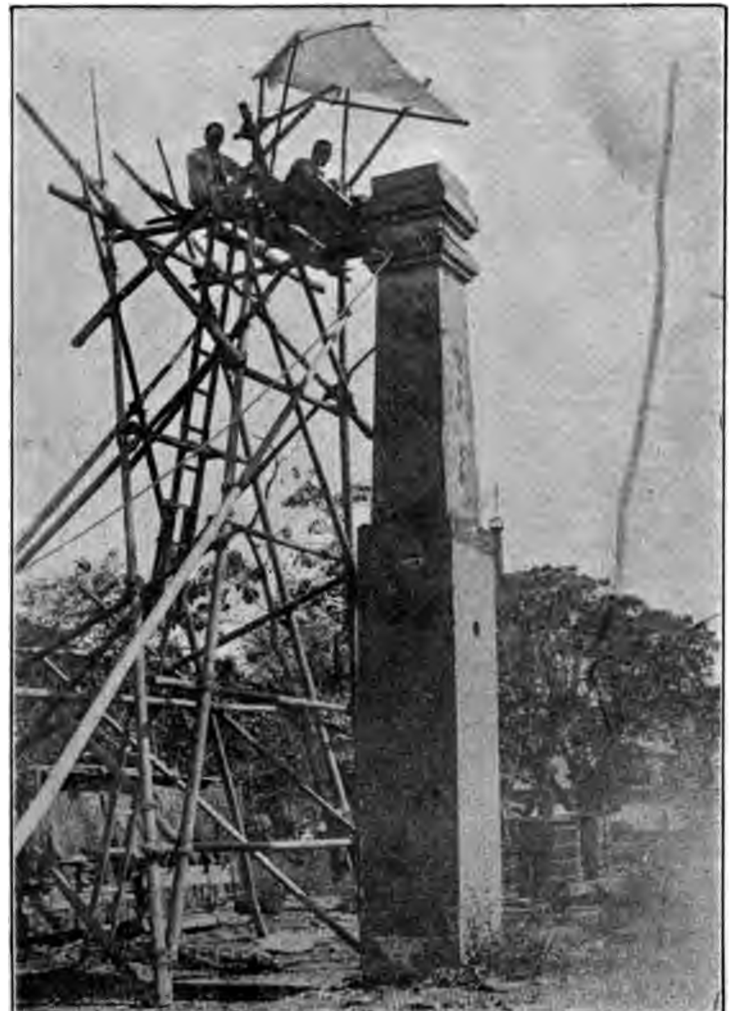
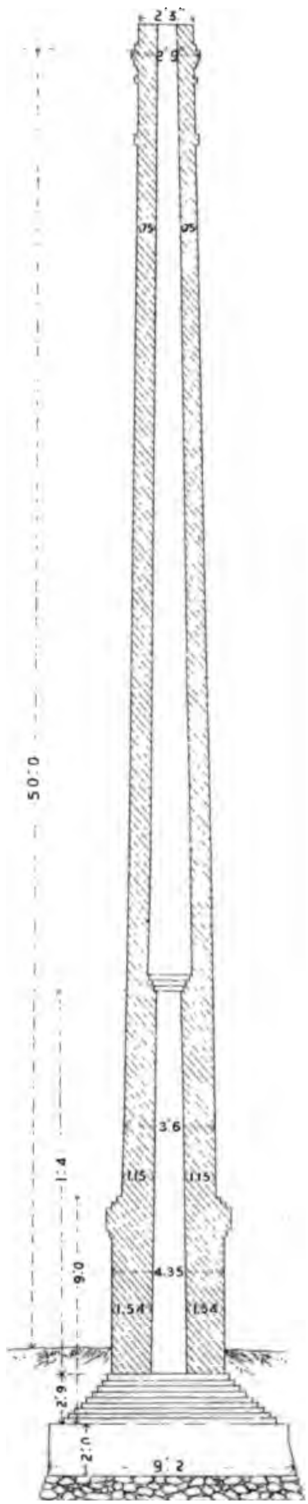


FIG. 3. CHIMNEY OF THE INSTITUTE OF MECHANICAL ENGINEERING, KYOTO IMPERIAL UNIVERSITY.

(Section.)

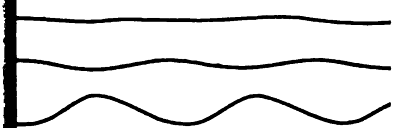


第三圖

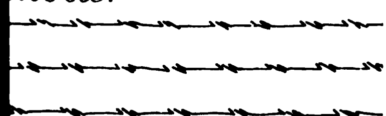
京都帝國大學器械工學教室附屬烟突斷面圖

VIBRATION OF THE (

KYOTO IMI



.68 sec.



.68 sec.

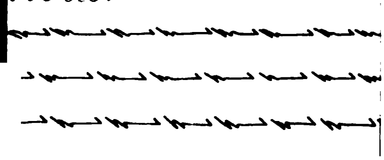
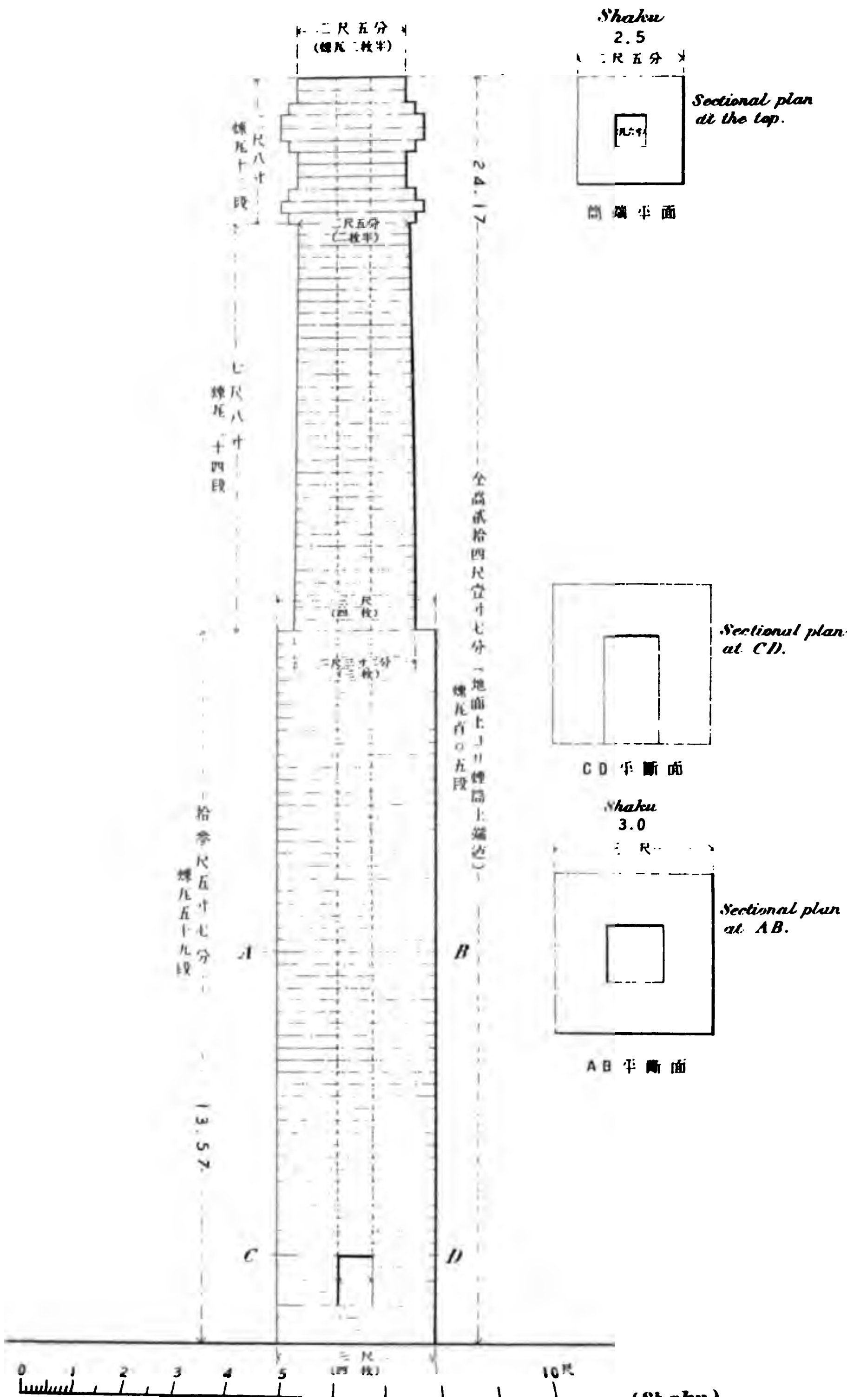


FIG. 6. CHIMNEY OF THE HYGIENICAL INSTITUTE, TOKYO IMPERIAL UNIVERSITY.

(Elevatiou and Sections.)

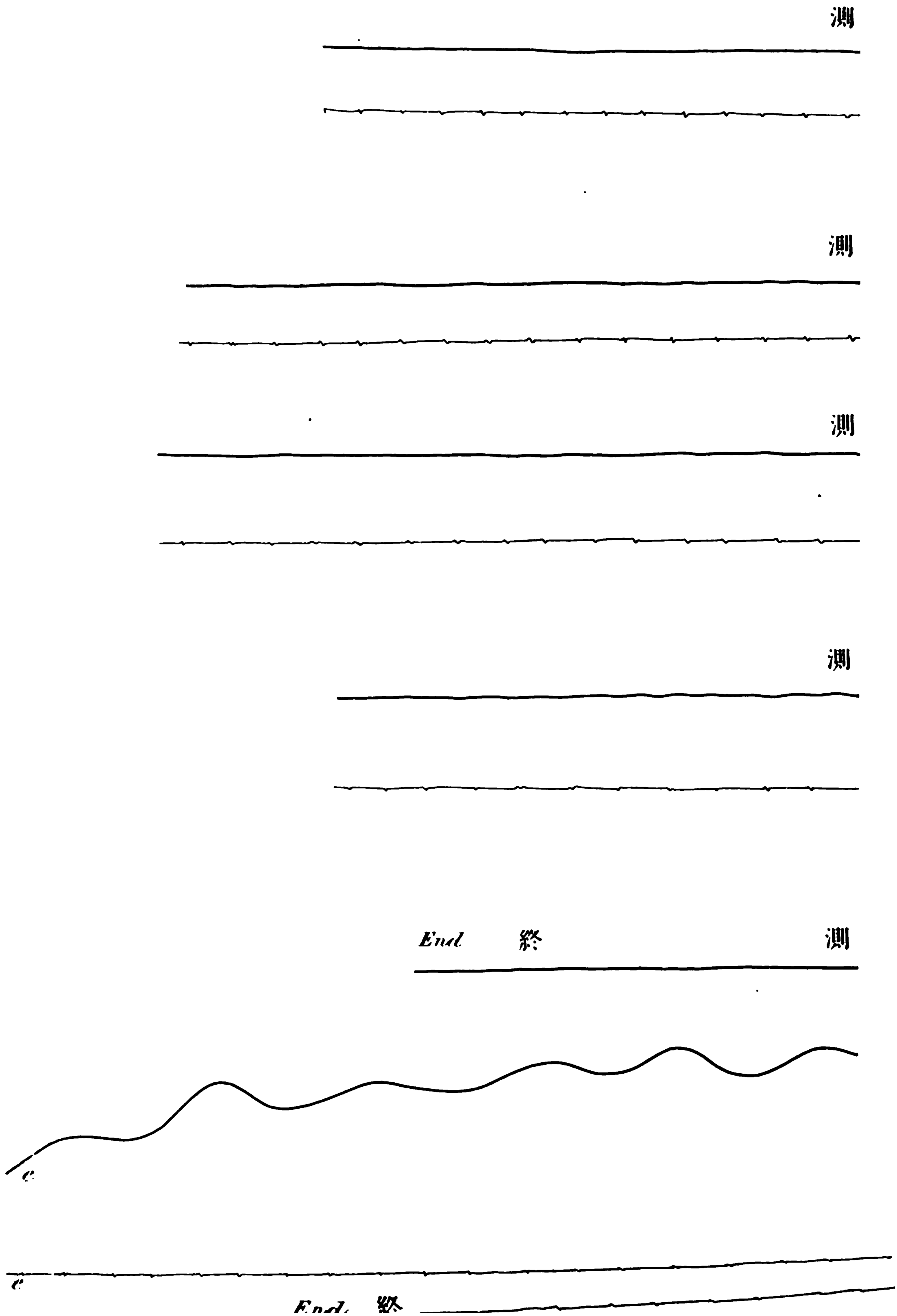
第六圖

醫科大學衛生學室燒掃跡之煙筒



衛生學教室燒跡烟突ノ振動（實大）

三十四年十月四日測驗



Note on the Vibration of Railway Bridge Piers.

By

F. Omori, *Rigakushi, Rigakuhakushi,*

Member of the Imperial Earthquake Investigation Committee.

With Plates XVII-XXII.

1. *Introduction.* In the course of the measurement of the movements of the different railway bridges,* I have often noticed the existence of certain longitudinal vibrations of a comparatively long period, which were found to be no other than those of the piers supporting the girders under examination; the pier motion, which consists of gentle shakings, being in some cases so large as to be distinctly felt without instrumental aid. The following preliminary series of the experiments carried on in Oct. and Nov., 1901, relates to six different piers of single track railway bridges in Central Japan. The knowledge of the movements of bridge piers would be important in determining their strength to resist earthquake shocks and wind pressure.

The measurement was made by means of a *vibration measurer*, (described in the *Publications*, No. 9) set up on a pier to be examined; the motion being recorded in three rectangular directions, namely, the vertical, transverse and longitudinal. The two last components are respectively the movements normal and parallel to the faces of a pier. In the following analysis of the diagrams of the pier motion, $2a$ denotes the range of vibration at the top of a pier.

2. *Tone-gawa Bridge, near Toride Station, Nippon Railway.* Oct. 21st, 1901.

The bridge consists of eight 200′ Double Warren trusses and twenty-two 60′ plate girders. The piers experimented upon were those respectively between the 1st and 2nd and between the 7th and

* See the *Publications*, No. 9.

8th 200′ trusses, counted from the Tokyo end; their elevations and sectional plans being given in Pl. XVII.

The motion of the piers was distinctly felt for some time before and after the passage of a train over the girders adjacent to them At the time of the experiments there was no wind.

The Pier between the 7th and 8th 200′ trusses.

The total height of the pier was 94.′2, of which 29.′35 was above the ground surface, while the remaining 64.′86 formed the well; the depth of the water being about 10′.

Expt. 1. Down goods train; engine No. 62.

Vertical vibration. There were only very slight traces of vertical motion, the average period being 0.41 sec.

Transverse vibration. The record-receiver was started 26 seconds before the arrival of the engine on the pier, but the vibrations were then already distinctly shown. During that preliminary portion the average period was 0.35 sec. In the principal portion, the max. $2a$ was 1.3mm, the average period being 0.42 sec. The motion died out very gradually.

Longitudinal vibration. Some slight traces of motion existed already at the start of the record-receiver. In the principal portion, the max. $2a$ was 0.8mm and the average period 0.87 sec.

Expt. 2. Up goods train; engine No. 55.

The train took 30 seconds to pass completely over the 8th 200′ girder, there being practically no motion during the first 2.0 sec. after the entrance of the engine on the latter. The motion was not yet ended at the 54th second after the start, when the clock-work of the record-receivér was stopped.

Vertical vibration. The motion was very slight.

Transverse vibration. In the most active part of motion, when the engine was passing over the pier, the max. $2a$ was 0.5mm and the average period 0.37 sec. The mean values of the period deduced from two successive series of 20 vibrations, when the train was passing on to the 7th 200′ girder, were 0.31 and 0.38 sec. respectively.

Longitudinal vibration. During the passage of the engine over the pier, the motion consisted entirely of vibrations of an average period of 0.33 sec. On the other hand, the succeding motion, which was slightly larger, consisted entirely of slow movements of an average period of 0.85 sec., the max.2a being 0.7mm. Toward the end, the vibrations had an average period of 0.45 sec., these being superposed more or less distinctly on slower ones.

The Pier between the 1st and 2nd 200′ Girders.

The total height of the pier is 121′.19, of which the well sinking amounts to 95′.57; the height above the ground surface being 19′.07. The diagrams obtained are reproduced in Pl. XXI.

Expt. 1. Up passenger train; engine No. 209.

Vertical vibration. There existed only very slight traces of motion, whose average period was 0.40 sec.

Transverse vibration. The passage of the train over the pier lasted 18.5 seconds; the vibrations lasted, however, for further 8.6 seconds. The motion was already distinctly shown 8.6 seconds before the entrance of the engine on the 2nd 200′ girder, when the record-receiver had been started. The motion in the preliminary portion, or before the passage of the engine over the pier, was already well pronounced (max. 2a = 0.3mm, average period = 0.38 sec.), being much greater than that during the passage of the wagons. In the most active portion, the max. 2a was 0.7mm, the average period being 0.37 sec.

Longitudinal vibration. The motion consisted of regular oscillations, whose max. 2a was 1.2mm, and whose average period in the most active portion was 0.86 sec. The amplitude gradually accumulated to the maximum, thenee again gradually decreasing.

Expt. 2. Down passenger train; engine No. 515.

The train passed over the pier in 22 seconds.

Vertical vibration. The motion was small but distinctly shown, the average period being 0.39 sec.

Transverse vibration. The earlier slight movements had an

average period of 0.79 sec. The motion in the principal portion was not uniform, but consisted of three different groups of maximum vibrations of which the 1st and 2nd were nearly alike. In the 1st group, which occurred immediately after the passage of the engine over the pier, the max. 2a was 0.5mm, the average period being 0.47 sec. In the 2nd group, the average period was 0.45 sec. In the 3rd group, the vibrations, which had an average period of about 0.87 sec. were superposed with others of about half the period. Toward the end, the average period was 0.83 sec.

The different maximum groups were evidently caused by the passage of the engines over the successive piers.

Longitudinal vibration. The max. 2a was 0.6mm, the average period being 0.91 sec. in the most active portion and 0.85 sec. toward the end.

3. *Ibi-gawa Bridge, (near Kuwana Station), Kansei Railway.*

The Ibi-*gawa* bridge on the Kansei Railway, between the stations of Kuwana and Nagashima, has a total span of 3263′ and consists of fifteen 200′ Double Warren girders and one 120′ Pratt truss, supported by fifteen piers numbered 1 to 15 from the Nagoya (Tokyo) to the Osaka end. The piers chosen for examination were Nos. 4 and 5, which are the most shaky among the series and whose height above the well was in each case 20′8″, the thickness at top and base being 10′ and 11′.87 respectively. (See Pl. XVIII.) On Nov. 12th 1901, when the experiments were made, the weather was stormy and it was very difficult to walk over the bridge; the winds having been particularly hard between 10 a.m. and 1½ p.m. The motion of the piers Nos. 4, 5, 10 and some others, which was caused by winds, was distinctly felt as slow transverse and longitudinal oscillations.

Pier No. 4.

The well is 84′.48 deep and consists of concrete filling an iron frame of two concentric ellipses joined together, whose outside and inside major diameters are 30′6″ and 25′4″ respectively. The diagrams of the transverse and longitudinal vibrations in the 1st and

2nd experiments are reproduced in Pl. XXII.

Expt. 1. Up train, composed of engine No. 44, eight passenger cars and two break-vans; $11\frac{1}{2}$ a.m. The engine passed over each of the adjacent 200′ girders in about 5.5 seconds.

Vertical vibration. Very slight.

Transverse vibration. For the sake of convenience, let t_5 denote the moment when the engine passed over the No. 5 pier and entered on the 5th girder. Between the start of the record-receiver, which was 7.7 seconds before t_5, and the latter moment, the max. 2a was 0.5mm and the average period 0.45 sec., the motion being active between 4.0 sec. and 0.9 sec. before t_5. The motion was then again active for an interval of 2.5 seconds between $t_5+1.7$sec. and $t_5+4.2$ sec.; the max. 2a being 0.67mm and the average period 0.55 sec. At $t_5+5.5$ sec., the engine passed over the No. 4 pier, or that under experiment; let this moment be denoted by t_4. The 3rd maximum motion occurred during a time interval of 3.3 seconds between $t_4+2.5$ sec. and $t_4+5.8$ sec.; the max. 2a being 0.73mm and the average period 0.45 sec. Again, denoting by t_3 the moment when the No. 3 pier was passed over, or putting $t_3=t_4+5.5$ sec., the 4th maximum occurred during a time interval of 2.2 seconds between $t_3+2.6$ sec. and $t_3+4.8$ sec.; the max. 2a being 0.53mm and the average period 0.46 sec. The next maximum motion was small and occurred at $t_3+9.4$ sec.; the max. 2a being 0.13mm and the average period 0.44 sec. Hereafter the movements became very slight. The train passed completely over the No. 4 pier at $t_3+3.6$ sec.

Longitudinal vibration. The motion was most active between t_4 and $t_4+8.8$ sec., the max. 2a being 1.0mm and the average period 0.88 sec. Before and after the above time interval the motion was small.

Expt. 2. Down train, composed of engine No. 41, eight passenger cars and two break vans; $11\frac{3}{4}$ a.m. The engine passed over the 4th girder in 3.4 seconds, while the whole train passed completely over the same in 6.4 seconds.

Vertical vibration. *Nil.*

Transverse vibration. As in the preceding experiment, the maximum transverse vibration occurred slightly after the moments of passage of the engine over the successive piers. The record-receiver of the instrument was started 3.6 seconds before t_3, when the engine was passing over the 3rd pier; t_3 having the same signification as above. The motion was active during the 1.7 sec. after t_3, the max. 2a being 0.67mm and the average period 0.34 sec. It was again active during the 1.6 sec. between $t_3+0.56$ sec. and $t_3+2.2$ sec.; the max. 2a being 1.3mm and the average period 0.33 sec. A second maximum group occurred for 1.4 sec. between $t_3+4.5$sec. and $t_3+5.9$ sec.; the max. 2a being 0.84mm and the average period 0.35 sec. Similarly there followed seven other maximum groups at an average interval of 2.3 seconds, the 2a becoming gradually smaller. Thus:—

in the 4th group, ... max. 2a = 0.67mm
" 5th " , ... " = 0.53 "
etc.

Longitudinal vibration. The max. 2a was 0.78mm, the average period being 0.82 sec.

Expt. 3. Effect of the winds.

Vertical vibration. *Nil.*

Transverse vibration. Max. 2a was about 0.6mm, the average period being 0.83 sec.

Longitudinal vibration. Max. 2a was 0.5mm, the average period being 0.77 sec.

Pier No. 5.

The well, which is 82'.33 deep, is elliptical in section and made of brick.

Expt. 1. Up train, composed of engine No. 40, eight passenger cars, two break vans, and five goods wagons.

Vertical vibration. *Nil.*

Transverse vibration. There were five different maximum groups of vibrations, whose average interval was 5.7 seconds; the 2nd group having occurred a little after the entrance of the engine on the 6th

girder. The maximum movements were as follows:

1st	group, ...	max. 2a = 0.4mm
2nd	„	„ 0.6 „
3rd	„	„ 0.6 „
4th	„	„ 0.5 „
5th	„	„ 0.5 „

The average period of vibration deduced from the 2nd and 3rd groups were 0.47 and 0.46 sec. respectively.

Longitudinal vibration. The max. 2a was 0.77mm, the average period being 0.92 sec.

Expt. 2. The effect of the winds.

Vertical vibration. *Nil.*

Transverse vibration. The max. 2a was about 0.5mm.

Longitudinal vibration. The max. 2a was 0.54mm, the average period being 0.89 sec.

4. *Tone-gawa Bridge, (near Maebashi Station), Nippon Railway.*

The bridge which spans over the Tone-*gawa*, in the immediate vicinity of the city of Maebashi, consists of two 200′ Double Warren girders and three 70′ plate girders. The river bed was partly dry and hard, consisting of boulders and gravels embedded in sand.

The pier experimented upon was No. 1 pier, or that between the two 200′ girders, whose height above the ground was 40′ 9″, the depth of the well being 38′. (See Pl. XIX). The pier, which had been damaged some years ago by floods, was repaired by means of iron bands, which bind the top portion cracked vertically down-wards to a distance of about 10′. The object of the following experiments, which were made on Nov. 25th 1901, was to examine the effect of the existence of the cracks on the vibration of the pier.

Expt. 1. Down train, composed of engine No. 38, and seventeen passenger cars; 9.50 a.m. The train ran very slowly, the engine and the entire train taking 5.7 and 14.5 seconds respectively to pass over the 1st 200′ girder.

Vertical vibration. The motion was slight but distinct; the max.

2a being 0.1mm and the average period 0.42sec.

Transverse vibration. The motion was most active when the engine was passing over the pier ; the max. 2a was 0.3mm and the average period 0.40 sec. When the train completely passed over to the 2nd 200′ girder, the average period was 0.24 sec.

Longitudinal vibration. The max. 2a was 0.3mm, and the average period 0.84 sec.

Expt. 2. Up train, composed of engine No.38, and eleven passenger cars ; 10.20 a.m.

Vertical vibration. The max. 2a was 0.1mm, the average period being 0.42 sec.

Transverse vibration. The max.2a was 0.2mm, the average period being 0.22 sec.

Longitudinal vibration. The max. 2a was 0.4mm, the average period being 0.85 sec. At first there were also small vibrations of an average period of 0.21 sec.

Expt. 3. Down train, composed of engine No. 38, two goods wagons, and eleven passenger cars ; 11.10 a.m.

Vertical vibration. The motion was nearly the same as in the preceding case ; the max. 2a being 0.15mm and the average period 0.44 sec.

Transverse vibration. The motion consisted of vibrations of an average period of 0.34 sec. (max. 2a = 0.4mm) superposed on those of an average period of 0.92 sec. (max. 2a = 0.5mm). Towards the end the average period was 0.25 sec.

Longitudinal vibration. The max. 2a was 0.4mm, the average period being 0.81 sec.

5. *Kizu-gawa Skew Bridge, Kansei Railway.*

The Kizu-*gawa* bridge on the Nagoya-Osaka line of the Kansei Railway, consists of a series of five spans as follows : one 100′ Warren girder (Nagoya end), one 200′ Pratt truss, one 100′ Warren girder, and two 70′ plate girders (Osaka end). The four piers were very tall, the height varying between 45′.5 and 65′. There was no well sinking, the

piers having been directly built on the solid native rocks. (See Pl. XX).

The pier experimented upon was the No. 1 pier, or the tallest one, which supports the 200′ truss and the 100′ girder at the Nagoya end. In the first of the following two experiments, the two horizontal pendulums of the *vibration measurer* were placed respectively at right angles and parallel to the length of the bridge; while in the second, they were placed in similar relations with respect to the pier plane.

Expt. 1. Up train, composed of engine No. 33, three goods cars, and 10 passenger wagons; 1.30 p.m.

Vertical vibration. The motion was slight (max. 2a = 0.15mm), the average period being 0.73 sec.

Transverse motion. The motion consisted of vibrations of an average period of 0.30 sec. (max. 2a = 0.5mm), mixed up with those of an average period of 0.16 sec. (max. 2a = 0.2mm).

Longitudinal vibration. The principal motion had an average period of 0.31 sec., the 2a being small.

There were also some traces of small vibrations of an average period of 0.14 sec.

Expt. 2. An express down train, composed of engine No. 36, and ten passenger cars; 2.10 pm.

Vertical vibration. The average period was about 0.53 sec., the 2a being very small.

Transverse vibration. There were two sets of vibrations, whose average periods were respectively 0.30 and 0.15 sec., the max. 2a in each being 0.1mm.

Longitudinal vibration. Very slight.

Abutment.

In the following experiment, the *vibration measurer* was put on the Nagoya end abutment.

Down train, composed of engine No. 38, one passenger car and eleven goods wagons.

The instrument indicated no motion.

6. *Summary of the Results.*

The elements of motion of the different bridge piers are collected in the following table.

TABLE I.

VIBRATIONS OF THE BRIDGE PIERS.

($2a$=Range of motion, or double amplitude, at the top of a pier.)

TONE-*GAWA* BRIDGE (TORIDE); PIER BETWEEN THE 7TH AND 8TH 200′ DOUBLE WARREN GIRDERS.

No. of expt.	Train	Vert. vibration.		Trans. vibration.		Long. vibration.		Engine.
		max 2a	Period	max. 2a	Period	max. 2a	Period	
		mm.	sec.	mm.	sec.	mm.	sec.	
1.	Down goods train	small	0.41	1.3	0.39	0.8	0.87	62
2.	Up „ „	„	—	0.5	0.35	0.7	{0.85 {0.39	555
	TONE-*GAWA* BRIDGE (TORIDE); PIER BETWEEN THE 1ST AND 2ND 200′ DOUBLE WARREN GIRDERS.							
1	Up passenger train.	Small	0.40	0.7	0.38	1.2	0.86	209
2	Down „ „	„	0.39	0.5	{0.46 {0.83	0.6	0.88	515
	IBI-*GAWA* BRIDGE (KUWANA); PIER NO. 4.							
1	Up passenger train.	Small	—	0.7	0.47	1.0	0.88	44
2	Down „ „	0	—	1.3	0.34	0.8	0.82	41
3	Winds.	0	—	0.6	—	0.5	0.77	—

IBI-*GAWA* BRIDGE (KUWANA); PIER NO. 5.

		mm.	sec.	mm.	sec.	mm.	sec.	
1	Up train.	—	—	0.6	0.47	0.8	0.92	40
2	Wind.	—	—	0.6	—	0.5	0.89	—

TONE-*GAWA* BRIDGE (MAEBASHI); PIER NO. 1. (CRACKED PIER).

1	Down train.	0.1	0.42	0.3	0.40 0.24	0.3	0.84	38
2	Up train.	0.1	0.42	0.2	0.22	0.4	0.85 0.21	38
3	Down train.	0.15	0.44	0.3 0.5 —	0.34 0.92 0.25	0.4	0.81	38

KIZU-*GAWA* BRIDGE; PIER NO. 1.

1	Up train.	0.15	0.73	0.5 0.2	0.30 0,16	Small „	0.31 0.14	33
2	Down train.	Small	0.53(?)	0.1 0.1	0.30 0.15	Small	—	36

Remarks.

(*a*) *Period and range of motion.* The vertical vibration was always very small, while the transverse and longitudinal vibrations were usually well pronounced, their ranges being nearly equal to each other.

With the exception of the Kizu-*gawa* pier, the periods of the *vertical* and *longitudinal* vibrations were nearly constant; the mean values being 0.41 and 0.85 sec. respectively. These are probably not the periods of the true elastic vibrations of the piers themselves, but are rather those of the rocking motion of the latter due to the vertical and transverse vibrations of the 200′ girders which rest upon them. Thus, taking averages from the five bridges of the Ibi (near Ōgaki, on the Tokaidō Railway), the Ibi (Kuwana), the Ōi, the Tone (Toride), and the 1st Ishikari-*gawa*, we obtain the periods of 0.40 and 0.90 sec. respectively for the *vertical* and *transverse* vibrations of the

200′ Double Warren girders, which are practically identical with the mean values of the *vertical* and longitudinal periods of the piers. The maximum 2a's of the pier motion was 0.15mm for the vertical and 1.2mm for the longitudinal component.

The periods of the transverse, or real elastic, motion of the different piers varied between 0.22 and 0.47sec.; the maximum range of motion varying between 0.1 and 1.3mm.

From what has been said above it is evident that the periods of vibration of the bridge piers are roughly speaking between 0.2 and 0.9 sec., that is to say, not very much different from the periods of motion in ordinary *weak* and *strong* earthquakes. At the time of a destructive earthquake, the motion of the piers would be much greater than that caused by ordinary railway traffic and the period may become upward of 1 sec. As, however, the period of destructive earthquake motion is generally between 1 and 2 sec., we may conclude that the bridge piers are, when considered with respect to their fracturing, to be regarded as *short columns*, and not as *long columns* like tall factory chimneys.

(*b*) *Effect of winds.* In the case of the Ibi-*gawa* bridge (Kuwana), the movements of the piers caused by strong winds were nearly the same as those due to the actual passage of the trains. In very violent storms the motion would be much greater and the range of the transverse and longitudinal vibrations may, when coupled with those produced by the passage of a train, amount to a few mm.

(*c*) *Iron frames.* The two piers, Nos. 4 and 5, of the Ibi-*gawa* bridge (Kuwana) were nearly alike, except that the former has elliptical iron frames embedded in the well. The motion of the No. 4 pier was, however, not less than that of the other. This seems to show that iron frames, unless very strong, have no sensible effect on the vibration phenomena of large masonry columns in which they are embedded. The following table, which has been constructed from the preceding, gives the maximum and mean values of the 2a and the period.

TABLE II.

MAXIMUM AND MEAN VALUES OF THE VIBRATIONS OF THE BRIDGE PIERS.

$2a$ = Range of motion, or double amplitude, at the top of a pier.
T = Complete period of vibration.

Bridge pier.	Vertical vibration.				Transverse vibration.				Longitudinal vibration.			
	Max. $2a$		T		Max. $2a$		T		Max. $2a$		T	
	Absolute.	Mean.	Max.	mean.	Absolute.	Mean.	Max.	Mean.	Absolute.	Mean.	Max.	Mean.
	mm.	mm.	sec.	sec.	mm.	mm.	sec.	sec.	mm.	mm.	sec.	sec.
Tone-*gawa* Bridge (Toride); pier between 7th and 8th 200′ girders.	Small	Small	—	0.41	1.3	0.9	0.33	0.38	0.8	0.8	0.87	0.86
Same bridge; pier between 1st and 2nd 200′ girders.	"	"	0.40	0.40	0.7	0.6	—	0.42	1.2	0.9	0.88	0.87
Ibi-*gawa* Bridge (Kuwana); Pier No. 4.	"	"	—	—	1.3	0.9	0.47	0.41	1.0	0.8	0.88	0.82
Same bridge; Pier No. 5.	"	"	—	—	0.6	0.6	—	0.47	0.8	0.7	0.92	0.91
Tone-*gawa* Bridge (Maebashi); Pier No. 1.	0.2	0.1	0.44	0.43	0.5	0.3	0.40	{0.24 / 0.37	0.4	0.4	0.84	0.83
Kizu-*gawa* Bridge; Pier No. 1.	0.2	—	0.73	0.63	0.5	0.3	0.31	0.21	Small	Small	—	{0.14 / 0.31

7. *Note on the longitudinal vibrations of bridge girders.*

The following table gives the pier motion indicated in the longitudinal vibration diagrams of some of the bridge *girders* measured in 1900 and 1901.

TABLE. III.

TRANSVERSE PIER VIBRATION DEDUCED FROM THE LONGITUDINAL MOTION DIAGRAMS OF THE DIFFERENT BRIDGE GIRDERS.

Bridge Pier and date of expt.	No. of expt.	Max. 2a. (mm.)	Period. (sec.)
Tone-gawa (Toride); 8th 200′ Double Warren girder. Oct. 21, 1901.	1	0.3	0.36
	2	0.4	0.37
	3	0.7	0.39
	4	0.6	0.38
	5	0.8	0.40
	6	0.7	0.40
	7	1.2	0.38
	Mean	**0.7**	**0.38**
Kizu-gawa ; 200′ Pratt truss. Nov. 7, 1901.	1	Small	0.22
	2	”	0.19
	3	”	0.20
	4	”	0.23
	5	”	0.19
	6	”	0.21
	Mean	—	**0.21**
Ibi-gawa (Kuwana); 200′ Double Warren girder. Nov. 12, 1901.	1	0.5	—
	2	0.4	0.43
	3*	Small	

Bridge. Pier and date of expt.	No of. expt.	max. 2a. (mm.)	Period (sec.)
Kuji-gawa ; 100′ Warren girder. Oct. 18, 1901.	1.	0.3	0.30
	2.	0.6	0.31
	3.	Small	0.38
	4.	0.5	0.28
	Mean	**0.4**	**0.32**
Tone-gawa (Maebashi); 70′ plate girder. Nov. 25, 1901.	1.	Small	0.23
	2.	”	0.20
	3.	”	0.20
	Mean	—	**0.21**
Ibi-gawa (Ōgaki); 1st 200′ Double Warren girder. April 16, 1900.	1.	0.35	0.32
	2.	0.3	0.33
	3.	0.7	0.36
	4.	—	0.33
	5.	0.2	0.30
	6.	—	—
	Mean	**0.4**	**0.33**
2nd Ishikari-gawa ; 70′ plate girder. Oct. 11, 1900.	1.	Small	0.16
	2.	”	0.17
	Mean	—	**0.17**

* Due to the winds.

From the above table it will be seen that the average period for the girders of the Tone-*gawa* (Toride), the Ibi-*gawa* (Kuwana), and the Kizu-*gawa* bridges are respectively 0.38, 0.43, and 0.21 sec.; these being exactly identical with the mean values of the periods of the transverse vibration of the corresponding bridge piers, given in Table II.

A striking fact, which is apparent from tables I and II is that the motion of a pier does not depend simply on its height above the well. Thus the motion of the pier of the Kizu-*gawa* bridge, whose height was 60′, was markedly smaller than that of those of the Tone-*gawa* (Toride) and the Ibi-*gawa* (Kuwana) bridges, although in the cases of the two latter bridges the heights of the piers above the river bed were much smaller and only about 20.′ The motion of the pier of the Tone-*gawa* bridge (Maebashi) was also very small. These peculiarities are obviously due to the fact that the river beds of the Kizu-*gawa* and the Tone-*gawa* (Maebashi) are hard, while the beds of the Ibi-*gawa* (Kuwana) and the Tone-*gawa* (Toride) are muddy and very soft. In other words, the piers with solid foundations are rigid; while those, whose foundations are weak, are very shaky.

From the above it is evident that a pier does not, in general, behave as if it were rigidly fixed to the ground at the surface of the latter. Thus, taking as examples the Kizu-*gawa* and the Tone-*gawa* (Toride) piers, we see that the period of the transverse vibrations are 0.21 and 0.38 sec.* respectively, while the heights of the piers above the ground are 60′ and 29′.35 respectively. If now h and h^1 denote the heights of the Kizu-*gawa* and the Tone-*gawa* piers, supposed to be of an equal and uniform section, we have

$$\frac{h^2}{h_1^2}=\frac{0.21}{0.38}.$$

Now the Kizu-*gawa* pier has no well at all; its thickness at the base being, however, nearly identical with that of the well of the Tone-*gawa* pier. For the sake of a very rough calculation, let us take

* Taking for the Tone-*gawa* bridge the pier between the 7th and 8th 200′ girders.

for h, not the actual height of $60'$, but an arbitrary value of $55'$, and we obtain

$$h_1 = h \times \sqrt{\frac{0.38}{0.21}} = 74';$$

that is to say, the pier, whose well sinking amounts to $64'.86$, vibrates about a point in it $45'$ below the ground surface as centre.

Tokyo. June 1902.

LIST OF PLATES.

In the vibration diagrams, Pls. XXI and XXII, the multiplication ratios are as follows:—

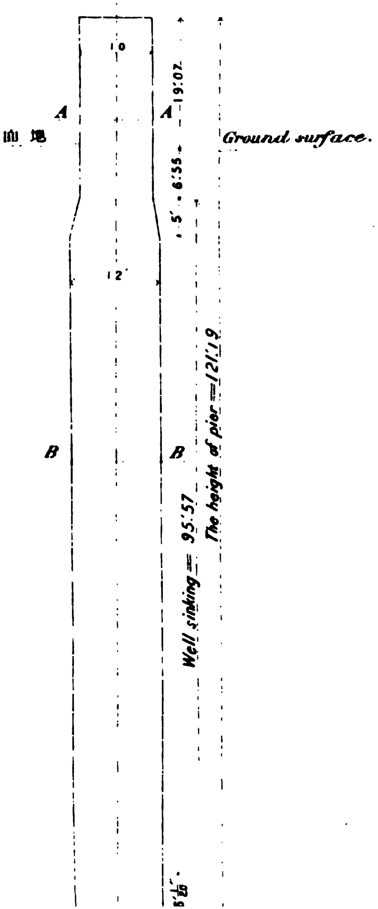
Vertical vibration	......	2	times;
Transverse ,,	......	1.5	,,
Longitudinal ,,	......	1.3	,,

Time marks. The value of two consecutive tick intervals, corresponding to one complete oscillation of the time-marking pendulum is 0.66 sec. in each case.

PIERS OF THE TONE-*GAWA* BRIDGE (TORIDE), NIPPON RAILWAY.

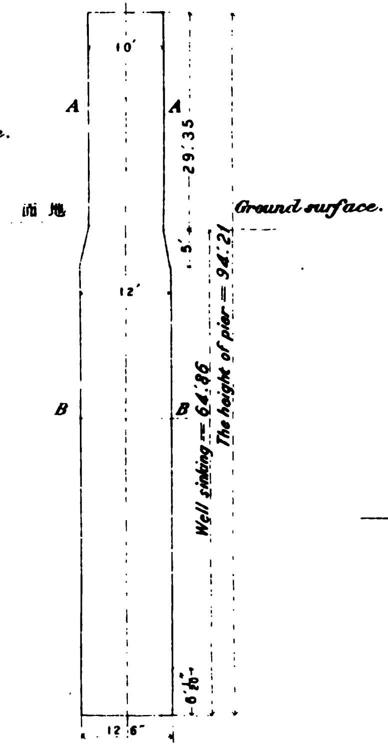
PIER BETWEEN THE 1ST AND 2DN 200′ GIRDERS.

Elevation.



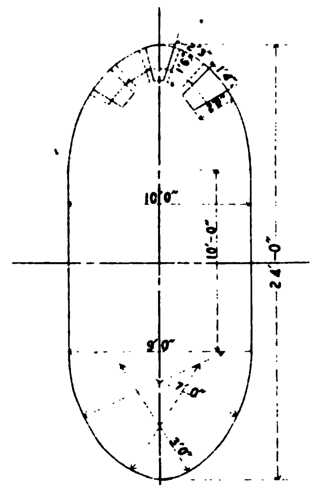
PIER BETWEEN THE 7TH AND 8TH 200′ GIRDERS.

Elevation.

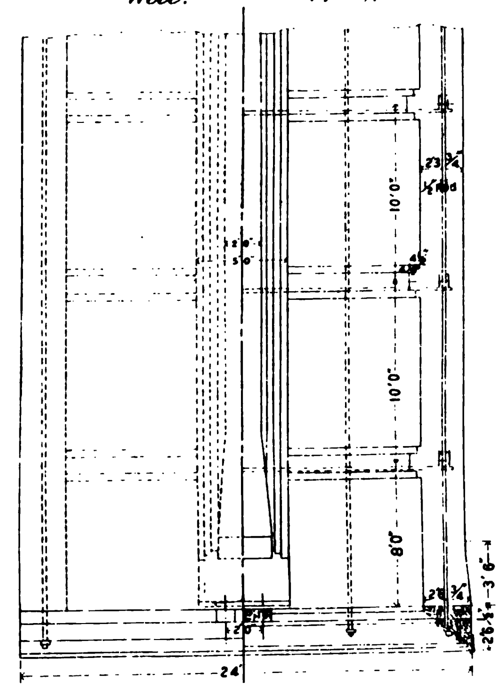


圖面断 *A.A.*

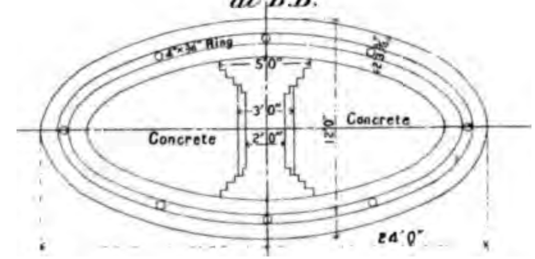
Sectional Plan at A.A.



Well. 筒井



Sectional Plan at B.B.



Scale:

Sectional Plan, Well: 1in = 10ft

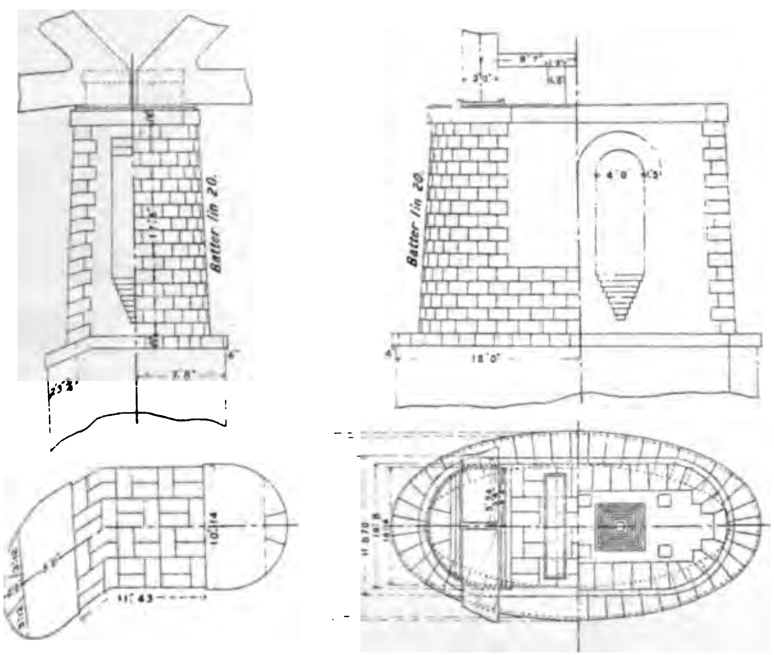
Elevation: 1in = 25ft

THE PIERS AND WELLS OF THE IBI-*GAWA* BRIDGE, (KUWANA), KANSEI RAILWAY.

關西鐵道揖斐川橋橋脚

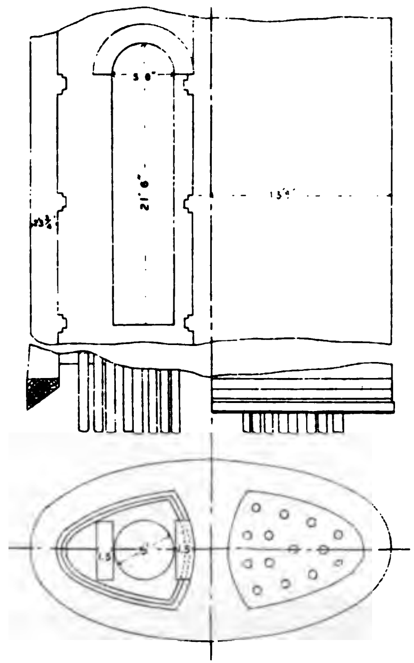
Pier

橋脚



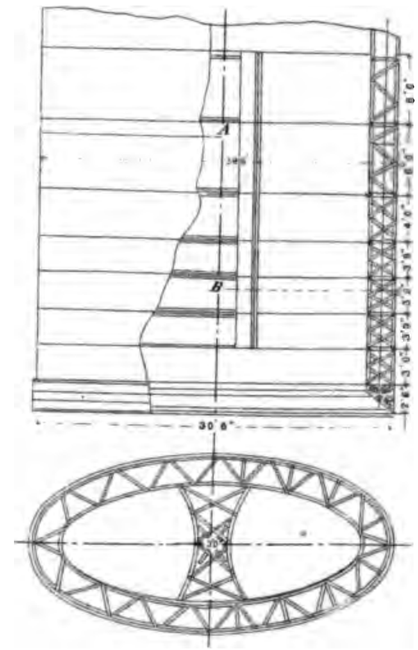
Brick Well

煉瓦井筒



Iron Well

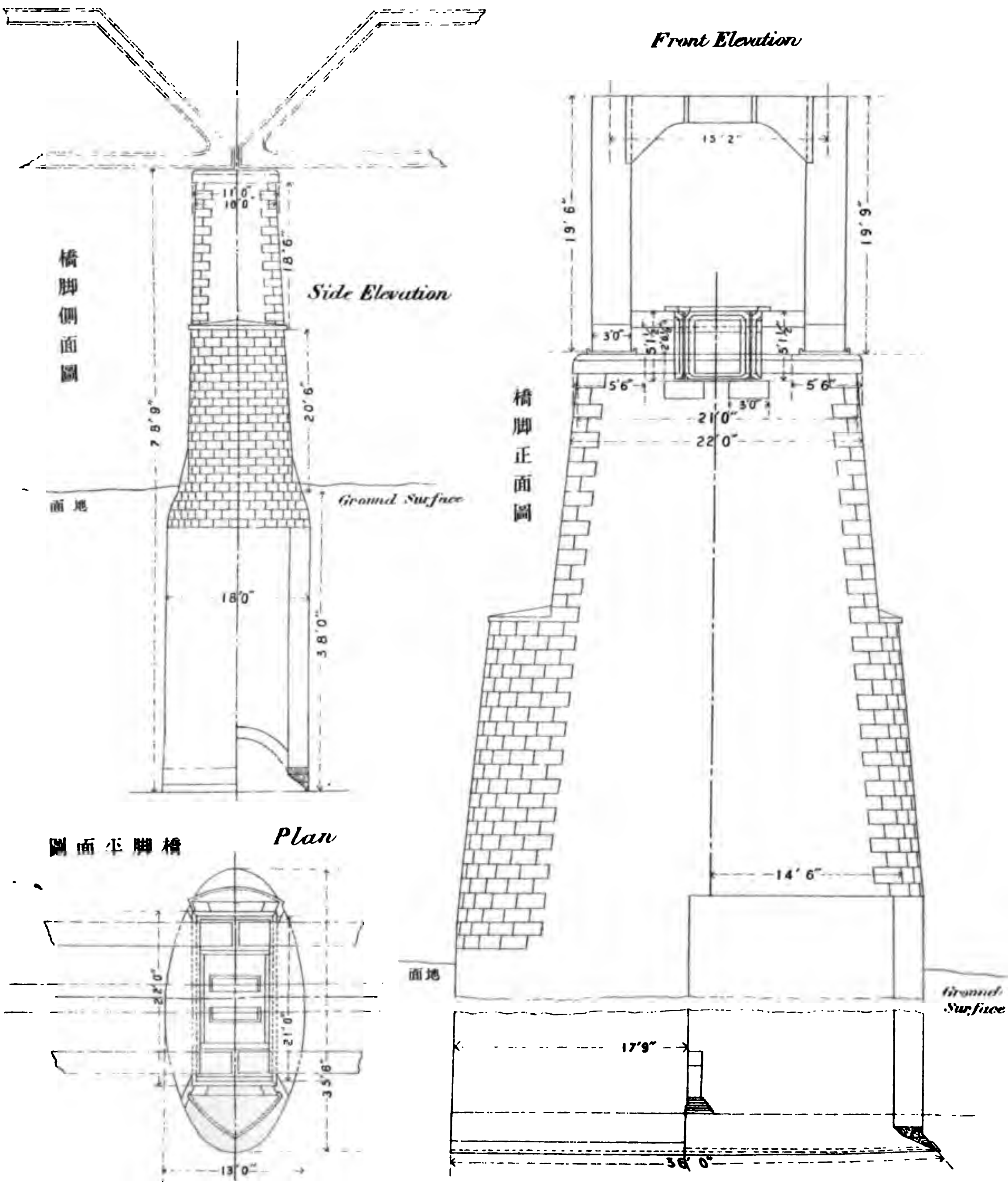
鐵製井筒



PIER No. 1 OF THE TONE-*GAWA* BRIDGE (MAEBASHI), NIPPON RAILWAY.

日本鐵道會社 両毛線利根川第壹橋脚之圖

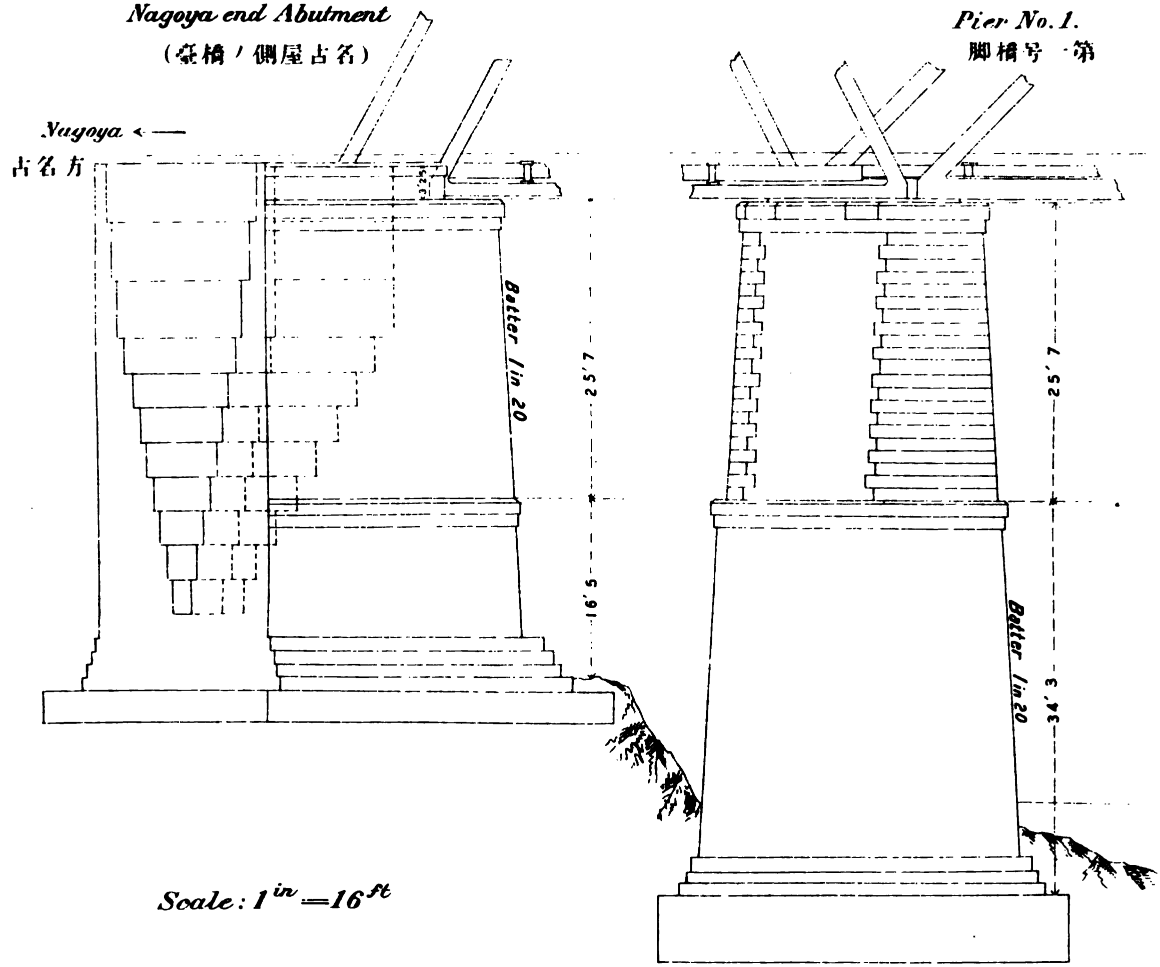
(徑間百尺鐵桁用橋脚)



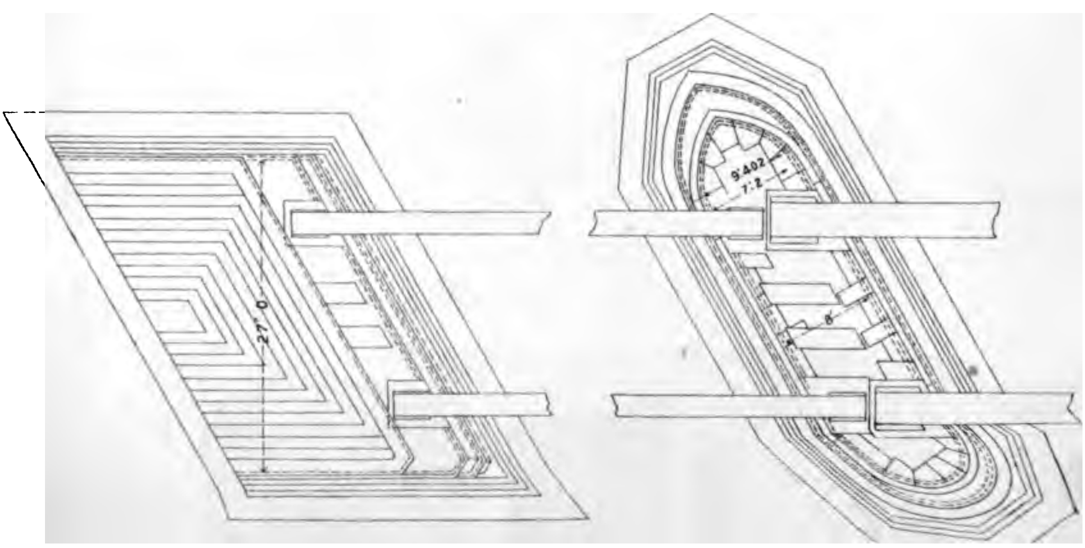
PIER AND ABUTMENT OF THE KIZU-*GAWA* BRIDGE, (KASAGI), KANSEI RAILWAY.

關西鐵道會社 木津川橋梁橋脚及橋臺圖

(縮尺以一吋爲十六呎)



Scale: 1^{in} = 16^{ft}

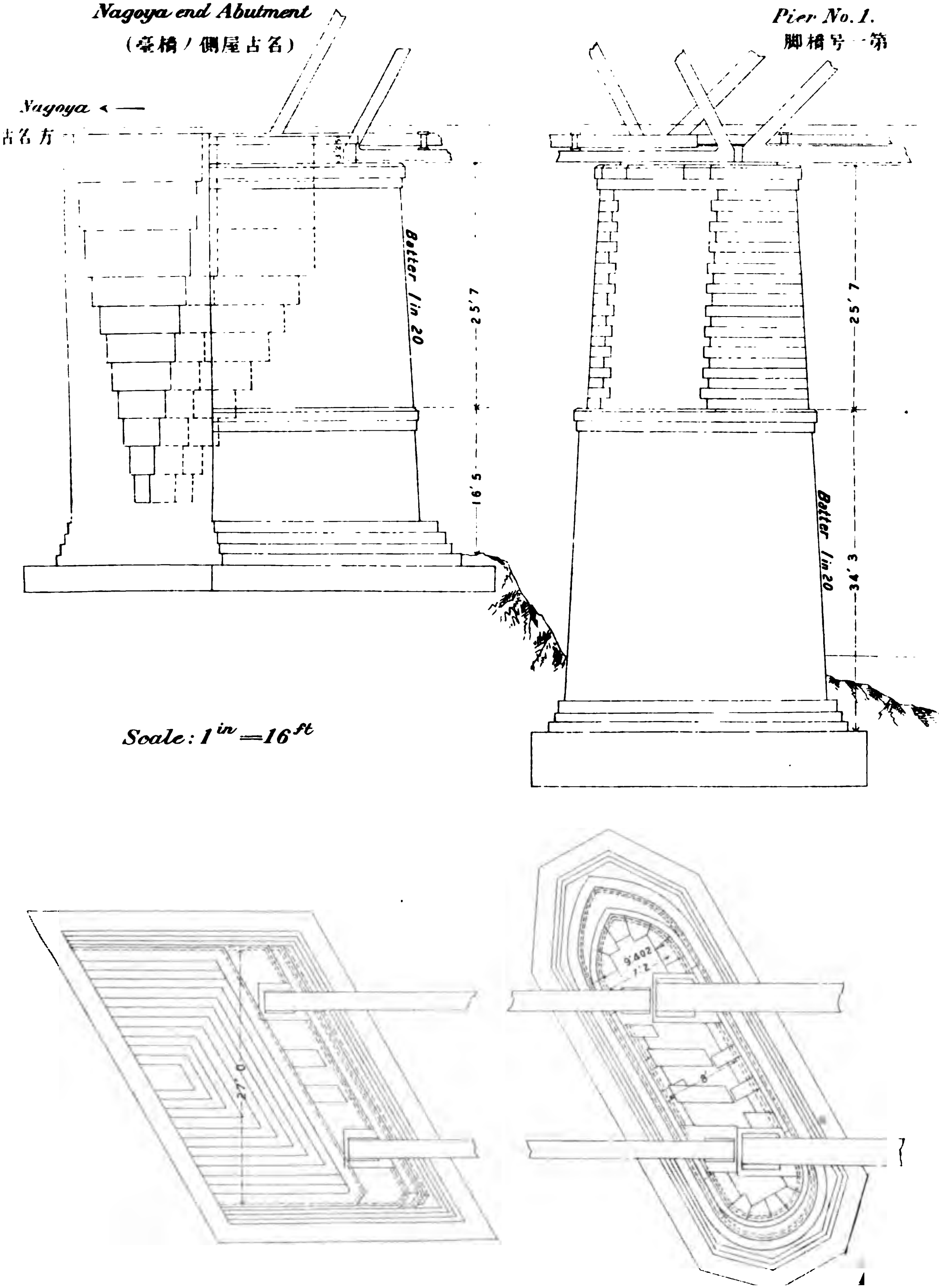


PIER AND ABUTMENT OF THE KIZU-*GAWA* BRIDGE,

(KASAGI), KANSEI RAILWAY.

關西鐵道會社 木津川橋梁橋脚及橋臺圖

(縮尺以一吋爲十六呎)



Motion of a Brick Wall Produced by Earthquakes.*

By

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Member of the Imperial Earthquake Investigation Committee.

The present note contains the results of the measurement of the motion of a wall produced by earthquakes; the wall chosen for examination being the eastern end wall † of the Natural History Museum, which is a two-storied brick building situated in the higher part of the grounds of the University, Tokyo. Fig. 2 (Pl. XXIII) gives the exterior view of the building, while Fig. 3 (Pl. XXIV) gives the vertical section of the wall. As will be seen from the latter figure, the total height of the wall, that is to say, the distance between the coping stone and the ground, amounts to 53 *shaku* ‡; the height of the ceiling of the second story above the ground being 37 *shaku.*

The motion of the wall was measured by means of a small horizontal pendulum seismograph set up on a strong wooden support fixed to the wall at a height of 31 *shaku* from the ground, fig. 1 (Pl. XXIII); the pointer of the instrument, which has a magnification of 5, recording the motion normal to the wall, or that in the E W direction. The records obtained at the Natural History Museum

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* See also the present Author's paper: "Earthquake Measurement in a brick building," the *Publications*, No. 4.

† The wall was originally intended to be a kind of partition wall separating the present building from its extension. The latter, however, never came into existence, the idea having since been abandoned.

‡ 1 *shaku* = 0.994 foot.

have been compared with the E W component diagrams given by a seismograph, also of 5-times magnification, in the Seismological Institute; it being assumed that the motion at the latter is identical with that at the basement of the Museum.

The record-receiver, or drum, of the seismograph at the Natural History Museum has a circumference of 668mm and made one revolution in about 30 seconds, the rate of motion being accurately gauged by means of a time-marking pendulum, whose one complete oscillation was made in 0.75 sec. Again the recording drum of the seismograph in the Seismological Institute has a circumference of 960mm and made one revolution in about 40 seconds, the period of the time-marking pendulum being 0.99 sec. Each instrument is automatically started at the time of an earthquake by means of an electric contact-maker, whose sensibility was purposely made not very great in order to exclude very slight earthquakes.

It was soon found that the movements of the wall in question was always much greater than those at the ground surface; consequently the seismograph in the Natural History Museum being much more sensitive than the other. Thus, during the five months between May 15th and Oct. 25th, 1892, twenty-three earthquakes were recorded at the Museum, of which only eleven were observed at the Seismological Institute. Tables I and II give respectively the date and the elements of motion of the 23 earthquakes; some of the illustrative diagrams being given in Pls. XXV and XXVI.

In the analysis of the seismograms, 2a denotes the range of motion, or double amplitude, of the vibration.

TABLE I.

LIST OF THE EARTHQUAKES OBSERVED.

No. of earthquake.	Date.	Time of occurrence.	Intensity.
1.	May 15th 1902;	8.50. 0 p.m.	Slight.
2.	„ 25th „	8.30. 0 p.m.	Weak.
3.	June 13th „	5. 1.25 a.m.	Slight.
4.	„ 20th „	5.49.19 p.m.	Weak.
5.	„ 23rd „	7.42.20 a.m.	„
6.	„ 24th „	9. 7.40 p.m.	Slight.
7.	July 1st „	2. 0.54 a.m.	„
8. *	„ 8th „	11. 8.36 p.m.	„
9.	„ 14th „	10.40. 7 p.m.	„
10.	„ 23rd „	11.52.54 p.m.	„
11.	„ 26th „	7.51. 2 a.m.	„
12. *	Aug. 4th „	1.56. 2 a.m.	„
13.	„ 7th „	0.35.55 p.m.	Weak.
14.	„ 8th „	8.36.53 a.m.	Slight.
15.	„ 25th „	9. 8.48 a.m.	„
16.	Sept. 12th „	4. 7.54 a.m.	„
17. *	„ 14th „	6.20.41 p.m.	„
18. *	„ 22nd „	5.43.25 a.m.	„
19. *	„ „ „	10 52.29 a.m.	„
20. *	„ 27th „	7.19.17 a.m.	„
21.	Oct. 12th „	10.23. 0 a.m.	„
22. *	„ 16th „	1.57.24 a.m.	„
23.	„ 25th „	9. a.m.	„

* Those *slight* earthquakes marked with *asterisks* were very small *unfelt ones*.

TABLE II.

EARTHQUAKE OBSERVATION AT THE NATURAL HISTORY MUSEUM AND AT THE SEISMOLOGICAL INSTITUTE.

{ 2a = Range of motion or double amplitude.
T = Complete period of vibration.

No. of earthquake.	Motion of the Wall. [Nat. Hist. Museum]				Motion of the ground. [Seismological Institute]			
	Total duration. (sec.)	Duration of Principal portion. (sec.)	Max. 2a (mm)	T (sec.)	Total duration. (sec.)	Duration of Principal portion. (sec.)	Max. 2a. (mm).	T (sec.).
1	94	29	0.40	0.31	91	9	0.04	0.18
2	100	40	1.20	—	—	—	—	—
3	80	17	0.08	0.29	—	—	—	—
4	117	68	0.80	0.34	—	17	0.12	0.18
5	184	86	3.60	0.35	—	23	{ 0.70 1.20 1.50	{ 0.19 0.39 0.66
6	—	—	0.32	—	—	—	—	—
7	59	14	0.50	0.25	42	11	0.12	0.19
8	40	—	Small.	0.38	—	—	Very gentle.	—
9	61	17	0.36	0.32	18	—	0.06	0.23
10	73	22	0.40	0.31	27	—	0.08	0.20
11	124	40	0.80	0.34	—	14	0.14	0.19
12	105	19	0.40	0.31	—	—	—	—
13	84	28	1.80	—	—	15	1.30	0.34
14	84	31	0.46	0.31	—	—	—	—
15	122	17	0.20	0.40	9	—	0.04	0.19
16	40	—	0.10	0.33	—	—	—	—
17	90	30	0.34	—	—	—	—	—
18	—	—	Very small.	—	—	—	—	—
19	127	—	0.10	0.31	—	—	—	—
20	165	37	0.40	0.45	25	7	0.04	0.18
21	97	21	0.46	0.30	—	—	—	—
22	84	15	0.26	0.31	—	—	—	—
23	81	40	0.30	0.30	22	—	0.06	—
Mean*	94 sec. (96 sec.)	36 sec. (32 sec.)	0.78 mm (0.58 mm)	0.33 sec.	33 sec.	14 sec.	0.29	{ 0.19 0.37 0.66

* The mean values of the elements of motion of the wall have been obtained by taking only the 11 quakes also recorded in the Seismological Institute. The mean values deduced from all the 23 quakes are closed within brackets.

NOTES.

Eqke No. 2. (Nat. Hist. Mus.) At the commencement there were traces of small vibrations of an average period of about 0.11sec.

Eqke No. 4. This was a moderate earthquake.

(Nat. Hist. Mus.) In the *preliminary tremor*, the motion consisted of small vibrations of an average period of 0.12 sec. During the first 6.2 sec. of the *principal portion*, these quick vibrations were superposed on principal vibrations, whose average period was 0.34 sec. In the *end portion*, the average period was 0.35 sec.

(Seism. Inst.) In the *principal portion*, the vibrations of an average period of 0.18 sec. (max. 2a = 0.12mm) were superposed on larger ones of an average period of 0.63 sec. (max. 2a = 0.4mm).

Eqke No. 5. This was a moderately sharp shock.

(Nat. Hist. Mus.) In the *preliminary tremor*, the max. 2a was 0.6mm and the average period 0.35 sec.; there being also small vibrations of an average period of 0.11 sec. The *principal portion* began with a single slow undulation of 2a = 7.6mm, period = 2.0 sec.; and the motion was most active for the first 10.5 seconds, during which the average period was 0.35 sec., the two maximum motions of 2a = 3.6mm and 2a = 3.4mm having occurred respectively at 1.5 sec. after the commencement, and at the end, of this epoch. In the succeding part, where the motion was much smaller, the average period was 0.33 sec. In the *end portion*, the average period was also 0.33 sec. As is usually the case with the records from the Nat. Hist. Museum, the motion presented a series of alternations of maximum and minimum groups. Thus the maximum groups, each containing 4 or 5 well pronounced vibrations, occurred at a mean interval of 4.8 seconds.

(Seism. Inst.) In the *preliminary tremor*, the max. 2a was 0.06 mm, the average period being 0.14 sec. The *principal portion*, began with a slow undulation of 2a = 10.4mm, period = 2.2 sec. The most active part of motion consisted of the vibrations of an average period of 0.19 sec., whose max. 2a of 0.7mm occurred at the 8th second

(after the commencement of the principal portion). From about the 9th second, there predominated the vibrations of an average period of 0.39 sec., of which the max. 2a of 1.2mm took place at the 10th second; these being mixed up with slower ones of an average period of 0.66 sec., whose max. 2a of 1.5mm occurred at the 15th second.

Eqke No. 9. (Nat. Hist. Mus.) The average period was 0.32 sec. in the *principal* and 0.31 sec. in the *end portion*. The maximum groups occurred at a mean interval of 4.3 seconds.

Eqke. No. 10. (Nat. Hist. Mus.) The maximum groups occurred at a mean interval of 3.0 seconds.

Eqke. No. 11. This was a moderate earthquake. (Nat. Hist. Mus. The max. 2a of 0.8mm occurred at the commencement of the *principal portion*, the motion being most active and nearly uniform for the first 20.2 seconds. The average period was 0.32 sec. in the *principal portion* and 0.35 sec. in the *end portion*.

Eqke No. 12. (Nat. Hist. Mus.) The average period was 0.31 sec. in the *principal portion* and 0.35 sec. in the *end portion*. The maximum groups occurred at a mean interval of 4.8 seconds.

Eqke No. 13. (Nat. Hist. Mus.) The maximum groups occurred at a mean interval of 4.7 seconds.

(Seism. Inst.) The most active vibrations had a max. 2a of 1.3mm and an average period of 0.18 sec.

Eqke No. 21. (Nat. Hist. Mus.) The average period was 0.30 sec. in the *principal portion*, and 0.33 sec. in the *end portion*. The max. 2a of 0.46mm occurred 11.3 seconds after the commencement.

Eqke No. 23. (Nat. Hist. Mus.) The average period was 0.30 sec. in the *principal portion* and 0.32 sec. in the *end portion*.

SUMMARY OF THE RESULTS.

Comparison of the motion of the wall with that of the ground. Taking the 11 earthquakes recorded at the two stations (Table II), we obtain the following results:—

Elements of earthquake motion.	Nat. Hist. Museum.	Seism. Institute.	Ratio, $\left(\frac{\text{Nat. Hist. Mus.}}{\text{Seism. Inst.}}\right)$
Total duration.	94 sec.	33 sec.	2.8
Duration of princ. portion.	36 sec.	14 sec.	2.6
Max. 2a.	0.78mm.	0.29mm.	2.7
Period.	0.33 sec.	0.19 ; 0.37 ; 0,63 sec.	——

Thus the duration and the range of motion of the wall of the Natural History Museum are nearly three times larger than those at the ground surface, or the Seismological Institute. The motion at the apex of the wall, where the latter is joined to the roof, will probably be about twice as great as that at the point where the seismograph has been fixed.

Motion of the wall. From Table II, it will be seen that the period of vibration of the wall is practically constant, the mean value being 0.33 sec. This shows that the wall behaves in earthquakes like an elastic spring and executes vibrations with its own period, whatever the period and amplitude of the ground motion may be, excepting in cases of very slow waves, say, of periods longer than 2 seconds, which are felt equally on the ground and at the top of the wall.

The motion of the wall was in each case not a uniform one, but presented always a series of maximum groups at fairly regular intervals. The average value of the intervals between the successive maxima was 4·3 seconds, each including some 13 vibrations. The occurrence of the different maximum groups is probably due to the relation between the elasticity and the dissipation coefficient of the brick work of the wall. There was usually no very predominating

single large motion, the amplitude in the successive maximum groups being nearly equal to each other.

The wall, which was evidently a very weak one, can be caused to move slightly by pushing with hand at regular intervals; the max. 2a of the vibrations thus produced was, in a trial, 0.08mm, the average period being about 0.36 sec., that is to say, practically equal to that of the movements caused by actual earthquakes.

Effect of wind. On Sept. 28th, 1902, the weather was stormy. In consequence of the trembling of the wall of the Natural History Museum caused by the impact of the winds, the contact-maker was brought into action, and the seismograph recorded movements, whose max. 2a was 0.06mm and whose average period was 0.32 sec.

Tokyo. Nov. 1902.

LIST OF PLATES.

Pl. XXIII. *Fig. 1.* The seismograph set up on a support fixed to the eastern outer wall of the Natural History Museum.

Fig. 2. The Natural History Museum. *a* indicates the position where the seismograph has been mounted.

Pl. XXIV. *Fig. 3.* The eastern outer wall of the Natural History Museum. Vertical section through the coping stone.

[*Seismograms ; EW component, multiplication* = 5.]

Pl. XXV. *Fig. 4.* The earthquake of June 23rd, 1902, at 7h 42 m 20 s. a.m.; *intensity = weak.*

(*a*) Record at the Seismological Institute.

(*b*) „ „ „ Nat. Hist. Museum.

Pl. XXVI. *Fig. 5.* Earthquake of July 23rd, 1902, at 11h 52m 54s p.m.; intensitly = *slight.*

(*a*) Record at the Seismological Institute.

(*b*) „ „ „ Nat. Hist. Museum.

Fig. 6. Earthquake of July 26th, 1902, at 7h 51m 2s a.m.; intensity = *slight.*

Record at the Nat. Hist. Museum.

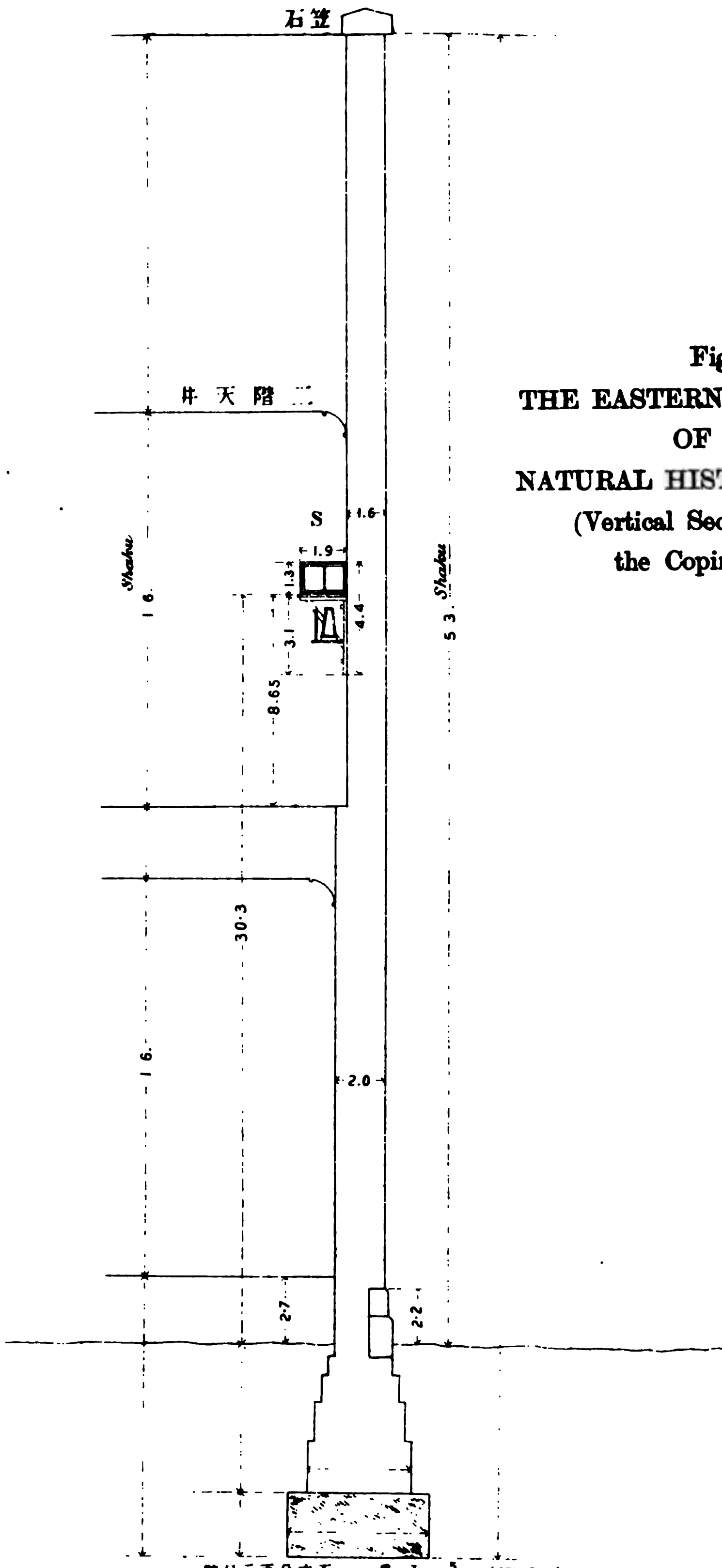
Time marks. The values of the complete oscillations of the time-marking pendulums, each corresponding to two consecutive tick intervals, are 0.99 sec. and 0.75 sec. respectively for the seismographs at the Seismological Institute and at the Natural History Museum.

[illegible]

Fig. 1. Seismograph.

Fig. 2. Natural History Museum.

Fig. 3.
THE EASTERN OUTER WALL
OF THE
NATURAL HISTORY MUSEUM
(Vertical Section through
the Coping Stone).



縮尺二百分之五 Scale $\frac{5}{200}$ (Shaku)

S ·· Seismograph. 地震計

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Fig. 1. Seismograph.

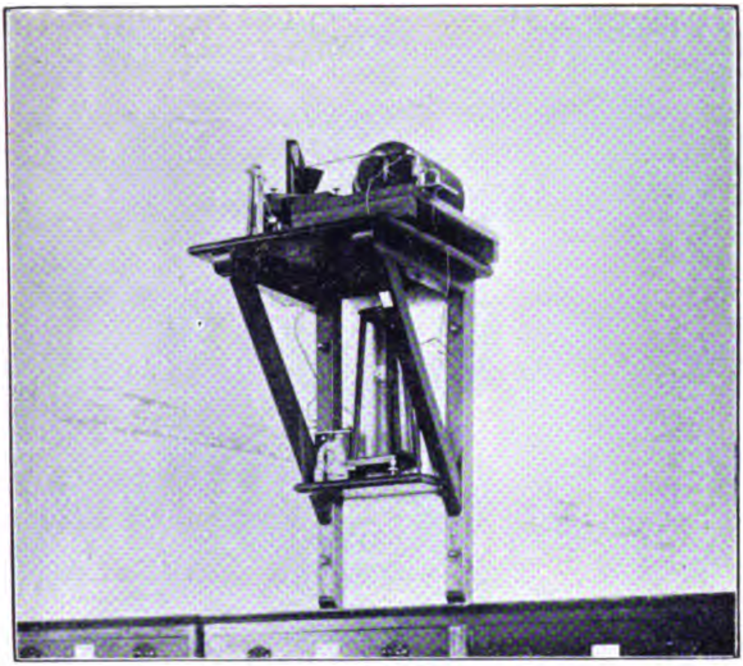

Fig. 2. Natural History Museum.

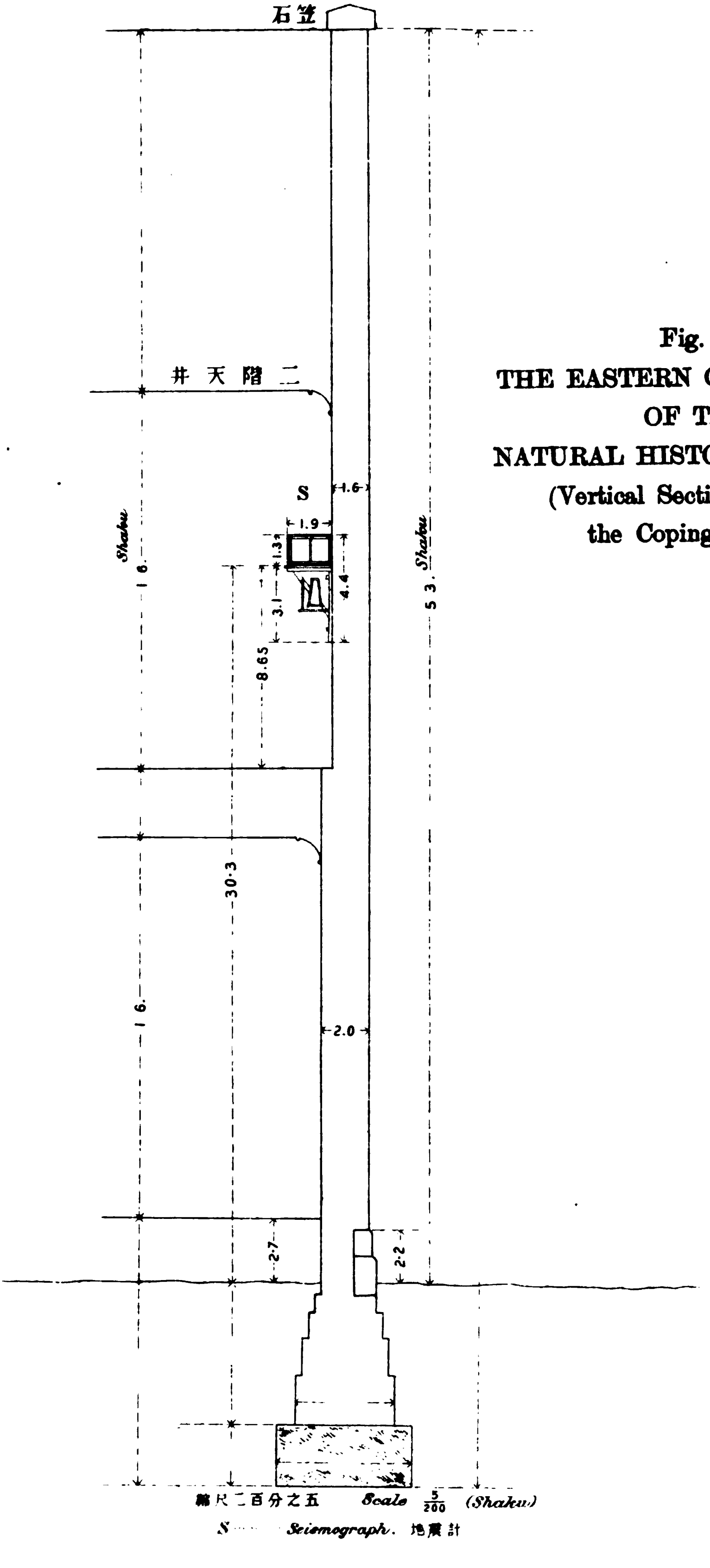

Fig. 3.
THE EASTERN OUTER WALL
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